A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota

MODULE 1

PRINCIPLES AND APPLICATION

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1 Introduction

The U.S. Department of Energy (DOE) is accountable to Congress and the public for the safe conduct of its activities, including facility operation, waste management and disposal activities, and remediation of environmental contamination. These routine activities may result in releases of radionuclides to the air and water, accumulation of radionuclides in soil and sediment, and the potential for plants, animals, and members of the public to be exposed to radiation. DOE Order 5400.5, "Radiation Protection of the Public and the Environment" (1990a), lists the environmental radiation protection requirements that DOE and DOE-contractor employees must meet to protect aquatic animals. In addition, dose limits below which deleterious effects on populations of aquatic and terrestrial organisms have not been observed, as discussed by the National Council on Radiation Protection and Measurements (NCRP 1991), and the International Atomic Energy Agency (IAEA 1992), are considered by DOE to be relevant to the protection of all aquatic and terrestrial biota on DOE sites.

1.1 Purpose

This DOE technical standard provides a graded approach (including screening methods and methods for detailed analyses) and related guidance that DOE and DOE contractors may use to evaluate compliance with specified limits on radiation dose to populations of aquatic animals, terrestrial plants, and terrestrial animals due to anthropogenic sources at DOE sites. Specifically, the technical standard provides dose evaluation methods that can be used to meet the requirements for protection of biota in DOE Orders 5400.1, "General Environmental Protection Program" (DOE 1990b), 5400.5 (DOE 1990a), and the dose limits for protection of biota developed or discussed by the NCRP (1991) and IAEA (1992). Accordingly, this technical standard uses the biota dose limits specified below within a graded approach to demonstrate that populations of plants and animals are adequately protected from the effects of ionizing radiation:

- **Aquatic Animals**. The absorbed dose to aquatic animals should not exceed 1 rad/d (10 mGy/d) from exposure to radiation or radioactive material releases into the aquatic environment. This dose limit is specified in DOE Order 5400.5.

- **Terrestrial Plants**. The absorbed dose to terrestrial plants should not exceed 1 rad/d (10 mGy/d) from exposure to radiation or radioactive material releases into the terrestrial environment.

- **Terrestrial Animals**. The absorbed dose to terrestrial animals should not exceed 0.1 rad/d (1 mGy/d) from exposure to radiation or radioactive material releases into the terrestrial environment.

Avoiding measurable impairment of reproductive capability is deemed to be the critical biological endpoint of concern in establishing the dose limits for aquatic and terrestrial biota. Module 1, Section 1.2.2 discusses this issue further. Guidance for interpreting and applying these dose limits with respect to the length of time and geographic area over which actual doses should be compared with the limits is provided in Module 2, Section 3.

DOE has proposed these dose limits for aquatic and terrestrial biota under proposed rule Title 10, Code of Federal Regulations, Part 834 (10 CFR 834), “Radiation Protection of the Public and the Environment” *(*DOE 1993). DOE has decided not to promulgate these dose limits until guidance for demonstrating compliance has been developed. Consequently, this technical standard was developed, in part, in response to comments and recommendations received by DOE through the proposed rule comment period. Principal themes in the comments included: (1) requests for development of cost-effective methods to support the use of DOE's existing and proposed biota dose limits, (2) support for a multi-tiered approach to include screening, (3) requests for guidance on biota monitoring, and (4) requests for development of a generic method to promote consistency, while retaining some flexibility for site-specific methods and information. These themes served as the guiding principles for development of the methods contained in this technical standard.

The specific methods and guidance in this technical standard are acceptable for use by DOE and DOE-contractors when evaluating doses to biota in relation to the above dose limits. The methods and guidance in this technical standard should also be useful to ecological risk assessors who must evaluate risks to biota from radionuclides that occur on DOE sites. Using the graded approach provided in this technical standard, risk assessors can use soil, sediment, and water radionuclide concentration data to determine whether radionuclide concentrations at a site are likely to result in doses in excess of those listed above and would, therefore, have the potential to impact resident populations of plants and animals. The methods can also give risk assessors an immediate qualitative assessment of the importance of doses of ionizing radiation to the resident receptors. The dose equations in this technical standard also provide methods of estimating upper-bound (e.g., conservatively derived) doses to specific plants and animals. Refer to Module 1, Section 3, for a description of intended and potential applications of the DOE graded approach.

1.2 Background

1.2.1 Increasing Interest and Need for Biota Dose Evaluation Methods

There is growing national and international interest in establishing a regulatory framework (e.g., to include standards or criteria) and supporting evaluation methodologies for demonstrating protection of the environment from the effects of ionizing radiation. Regarding environmental protection, the ICRP statement that "...if man is adequately protected then other living things are also likely to be sufficiently protected" (ICRP 1977; 1991) uses human protection to infer environmental protection from the effects of ionizing radiation. This assumption is most appropriate in cases where humans and other biota inhabit the same environment and have common routes of exposure, and less appropriate in cases where human access is restricted or pathways exist that are much more important for biota than for humans. The inclusion of radiation as a stressor within ecological risk assessments is also a consideration. Ecological risk assessments at contaminated sites being considered for remediation under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) generally require an assessment of all stressors, including radiation. Assessments of radiation impacts on contaminated ecosystems are currently underway in the U.S. under CERCLA regulations (EPA 1988).

Nationally and internationally, no standardized methods have been adopted for evaluating doses and demonstrating protection of plants and animals from the effects of ionizing radiation. In 1999, the IAEA convened a technical committee examining protection of the environment from the effects of ionizing radiation and provided recommendations and discussion points for moving forward with the development of protection frameworks and dose assessment methods. The resulting IAEA Technical Document, "Protection of the Environment from the Effects of Ionizing Radiation" (1999) references multi-tiered screening as a potentially cost-effective and easy way of demonstrating compliance with radiation criteria for protection of biota. The IAEA has subsequently hosted a series of Specialists' Meetings on radiological protection of the environment, and the Nuclear Energy Agency (NEA) and the ICRP have sponsored a series of fora on this issue. It is hoped that the methods and guidance provided in this DOE technical standard will serve as a platform for national and international discussion of radiation protection frameworks, standards, and dose assessment methods for biota.

Benefits of a Screening Process

"A multi-tiered screening approach is normally used in ecological risk assessments. Screening may also be a potentially cost-effective and easy way of demonstrating compliance with radiation criteria or standards for protection of the environment. Screening values should be used to identify radionuclides in situations of concern, and to determine whether these radionuclides warrant further assessment, or if they are at levels that require no further attention. In practice, this initial screening is expected to be sufficient in the majority of cases. When initial screening fails, additional analysis or assessment may be needed. A two- or three-tiered scheme would help ensure that the magnitude of the assessment effort would be scaled to the likelihood and severity of environmental impacts."

From: IAEA-TECDOC-1091, Protection of the Environment from the Effects of Ionizing Radiation: A Report for Discussion (July 1999)

1.2.2 Basis for Biota Dose Limits Applied in this Technical Standard

A dose limit for controlling radiological impacts from DOE activities to native aquatic animals is specified in DOE Order 5400.5. At present, DOE Orders do not specify dose limits for terrestrial organisms. However, an intended objective of DOE Orders 5400.1 and 5400.5 is to protect the aquatic and terrestrial environment, including populations of plants and animals, within and beyond the boundaries of DOE sites from impacts of routine DOE activities. The dose limits in this technical standard are consistent with (a) the intent of DOE Orders 5400.1

and 5400.5, (b) the dose limit for aquatic animals specified in DOE Order 5400.5, and (c) findings of the IAEA and NCRP regarding doses below which deleterious effects on populations of aquatic and terrestrial organisms have not been observed. They are also consistent with the intent of the IAEA document, “The Principles of Radioactive Waste Management” (IAEA 1995), in which Principle 2 states that “radioactive waste shall be managed in such a way as to provide an acceptable level of environmental protection.” The background for the dose limits for aquatic and terrestrial biota is briefly discussed below. These dose limits represent expected safe levels of exposure, and are consensus No Adverse Effects Levels (NOAELs) for effects on population-relevant attributes in natural populations of biota.

1.2.2.1 Aquatic Organisms

At the request of DOE, the NCRP (1991) reviewed the literature on the effects of radiation on aquatic organisms and prepared a report on the then-current understanding of such effects. The report also provided guidance for protecting populations of aquatic organisms, concluding that a chronic dose of no greater than 1 rad/d (0.4 mGy/h) to the maximally exposed individual in a population of aquatic organisms would ensure protection of the population.

The IAEA examined and summarized the conclusions regarding aquatic organisms of several previous reviews (IAEA 1992):

- Aquatic organisms are no more sensitive than other organisms; however, because they are poikilothermic animals, temperature can control the time of expression of radiation effects.

- The radiosensitivity of aquatic organisms increases with increasing complexity, that is, as organisms occupy successively higher positions on the phylogenetic scale.

- The radiosensitivity of many aquatic organisms changes with age, or, in the case of unhatched eggs, with the stage of development.

- Embryo development in fish and the process of gametogenesis appear to be the most radiosensitive stages of all aquatic organisms tested.

- The radiation-induced mutation rate for aquatic organisms appears to be between that for *Drosophila* (fruit flies) and mice.

Furthermore, the 1992 review found that the conclusions of an earlier IAEA review (1976) were still supported; namely, that appreciable effects in aquatic populations would not be expected at doses lower than 1 rad/d (10 mGy/d) and that limiting the dose to the maximally exposed individuals to less than 1 rad/d would provide adequate protection of the population.

1.2.2.2 Terrestrial Organisms

The IAEA (1992) summarized information about the effects of acute ionizing radiation on terrestrial organisms as follows:

- Reproduction (encompassing the processes from gametic formation through embryonic development) is likely to be the most limiting endpoint in terms of survival of the population.
- Lethal doses vary widely among different species, with birds, mammals, and a few tree species being the most sensitive among those considered.
- Acute doses of 10 rad (100 mGy) or less are very unlikely to produce persistent and measurable deleterious changes in populations or communities of terrestrial plants or animals.

The IAEA (1992) also summarized information about the effects of chronic radiation on terrestrial organisms:

- Reproduction (encompassing the processes from gametogenesis through embryonic development) is likely to be the most limiting endpoint in terms of population maintenance.
- Sensitivity to chronic radiation varies markedly among different taxa; certain mammals, birds, reptiles, and a few tree species appear to be the most sensitive.
- In the case of invertebrates, indirect responses to radiation-induced changes in vegetation appear more critical than direct effects.
- Irradiation at chronic dose rates of 1 rad/d (10 mGy/d) or less does not appear likely to cause observable changes in terrestrial plant populations.
- Irradiation at chronic dose rates of 0.1 rad/d (1 mGy/d) or less does not appear likely to cause observable changes in terrestrial animal populations. The assumed threshold for effects in terrestrial animals is less than that for terrestrial plants, primarily because some species of mammals and reptiles are considered to be more radiosensitive.
- Reproductive effects on long-lived species with low reproductive capacity may require further consideration.

The NCRP and IAEA concluded for aquatic organisms and the IAEA concluded for terrestrial organisms that the statement by the ICRP (1977; 1991), "...if man is adequately protected, then other living things are also likely to be sufficiently protected" was reasonable within the limitations of the generic exposure scenarios examined. A similar assessment was made at a DOE-sponsored workshop (Barnthouse 1995) held to evaluate the adequacy of existing effects data and approaches to radiation protection of aquatic and terrestrial organisms to support moving forward with setting regulatory limits. DOE workshop participants agreed that protecting humans generally protects biota, except under the following conditions: (1) human access to a contaminated area is restricted but access by biota is not restricted, (2) unique exposure pathways exist for plants and animals that do not affect exposure of humans, (3) rare or endangered species are present, or (4) other stresses on the plant or animal population are significant.

1.2.2.3 Additional Summaries and Reviews of Radiation Effects Data on Biota Confirming NCRP and IAEA Findings

UNSCEAR. In 1996, the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) summarized and reviewed information on the responses to acute and chronic radiation of plants and animals, both as individuals and as populations (UNSCEAR 1996). The conclusions from the UNSCEAR review were consistent with findings and recommendations made earlier by the NCRP and IAEA concerning biota effects data and appropriate dose limits for protection of biota. In 2002, UNSCEAR reported that these dose rate criteria (1 rad/d for aquatic animals and terrestrial plants; 0.1 rad/d for terrestrial animals) remain defensible for protection of populations of plants and animals. The UNSCEAR plans to develop a new scientific annex to further address radioecology and effects of radiation on the environment (Gentner 2002).

UK Environment Agency. In 2001, the Environment Agency of the United Kingdom (UK) conducted a review of the available body of radiation effects data on biota (Copplestone et al. 2001). They concluded that it is unlikely that there will be any significant effects in:

- populations of freshwater and coastal organisms at chronic dose rates below 400 uGy/h (or 1 rad/d; 10 mGy/d);

- terrestrial plant populations at chronic dose rates below 400 uGy/h (or 1 rad/d; 10 mGy/d); and

- terrestrial animal populations at chronic dose rates below 40 uGy/h (or 0.1 rad/d; 1 mGy/d).

It is noteworthy that the UK Environment Agency's review findings are largely consistent with the findings and biota dose recommendations of the NCRP, the IAEA, and UNSCEAR cited above. Additionally, they concluded that it is unlikely that there will be any significant effects in populations of organisms in the deep ocean at chronic dose rates below 1,000 uGy/h (or 2.5 rad/d; 25 mGy/d).

ACRP. In 2002, the Advisory Committee on Radiation Protection (ACRP), charged with providing advice to the Canadian Nuclear Safety Commission (CNSC) regarding approaches needed for the radiological protection of the environment, provided recommendations concerning appropriate dose rate criteria for protection of biota. The ACRP recommended that the generic dose rate criterion for protecting biota should be in the range of 1-10 mGy/d (0.1-1 rad/d). The ACRP indicated that this dose rate criterion is based on population-level effects and, given the current state of knowledge and consensus views of radiation effects on biota, represents the level at which ecosystems will suffer no appreciable deleterious effects. The criterion is specified in terms of daily dose rather than annual dose. The intent is to avoid, for example, what would be the annual dose at this dose rate criterion being received in a few days. The ACRP further recommended that there should be some flexibility in the averaging time used in interpreting this dose rate criterion (CNSC-ACRP 2002).

1.2.2.4 Application of Biota Dose Limits as "Dose Rate Guidelines" for Evaluating Doses to Biota

The biota dose limits specified in this technical standard are based on the current state of science and knowledge regarding effects of ionizing radiation on plants and animals. They should not be interpreted as a "bright line" that, if exceeded, would trigger a mandatory regulatory or remedial action. Rather, they should be interpreted and applied more as "Dose Rate Guidelines" that provide an indication that populations of plants and animals could be impacted from exposure to ionizing radiation and that further investigation and action is likely necessary.

1.2.3 Protection of Populations

The intent of the graded approach (i.e., the screening and analysis methods) in this technical standard is to protect populations of aquatic animals, terrestrial animals, and terrestrial plants from the effects of exposure to anthropogenic ionizing radiation. As noted above, certain taxa are more sensitive to ionizing radiation than others. Based on this observation, it is generally assumed that protecting the more sensitive taxa will adequately protect other, less sensitive taxa. Hence, in cases where site-specific evaluations may be required, receptors should be selected that (1) are important to the structure and function of the community, (2) are expected to receive a comparatively high degree of exposure (e.g., expected to receive a radiation dose to reproductive tissues which is relatively high per unit of radionuclide present in the ecosystem, in comparison with other receptors in the same community), and (3) have a comparatively high degree of radiosensitivity (e.g., radiation effects of concern occur at relatively low doses, in comparison with other receptors in the same community). Figure 1.1 shows the relative radiosensitivity of various taxa for both aquatic and terrestrial systems.

Participants at the DOE-sponsored workshop to evaluate the adequacy of existing effects data and approaches to radiation protection of aquatic and terrestrial organisms (Barnthouse 1995) concluded that existing data support the application of recommended dose limits to representative rather than maximally exposed individuals within populations of plants and animals. Participants concluded that exposure below the recommended dose limits would not cause adverse effects at the population level, even though some individuals within the population might be adversely affected.

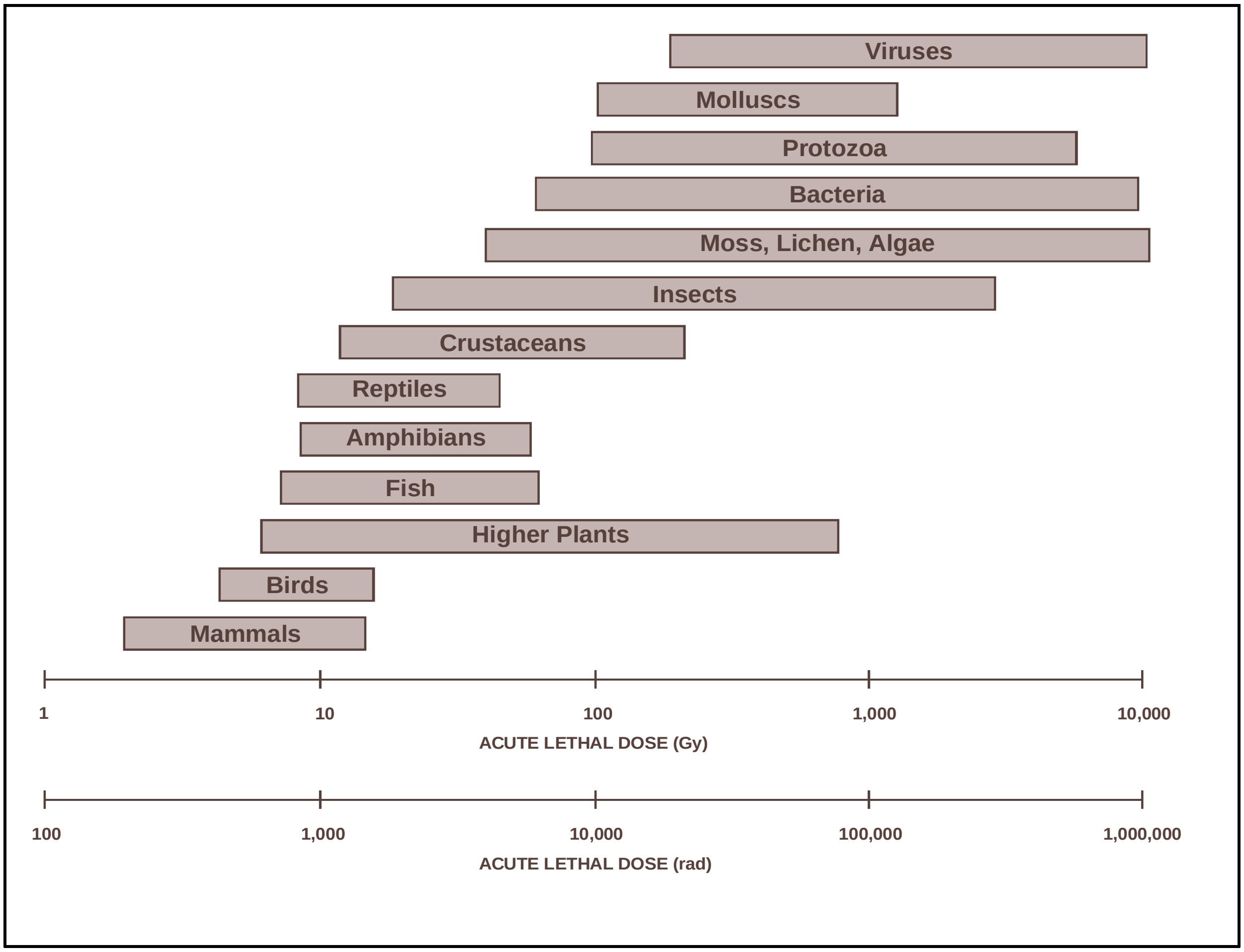


Figure 1.1 Approximate Acute Lethal Dose Ranges for Various Taxonomic Groups
Source: Whicker and Schulz 1982; UNSCEAR 1996.

2 *Overview of the DOE Graded Approach*

DOE's graded approach for evaluating radiation doses to aquatic and terrestrial biota consists of a three-step process which is designed to guide a user from an initial, conservative general screening to, if needed, a more rigorous analysis using site-specific information (Figure 2.1). The three-step process includes: (1) assembling radionuclide concentration data and knowledge of sources, receptors, and routes of exposure for the area to be evaluated; (2) applying an easy-to-use general screening methodology that provides limiting radionuclide concentration values (i.e., Biota Concentration Guides - BCGs) in soil, sediment, and water; and (3) if needed, conducting an analysis through site-specific screening, site-specific analysis, or an actual site-specific biota dose assessment conducted within an eco-risk. Any of the steps within the graded approach may be used at any time, but the general screening methodology will usually be the simplest, most cost-effective, and least time-consuming. Table 2.1 provides a summary of DOE's graded approach.

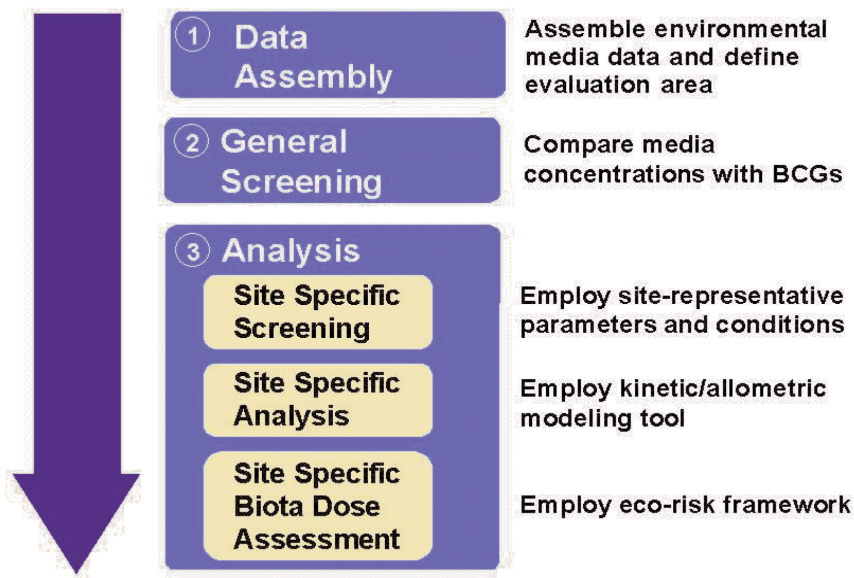


Figure 2.1 Overview of the DOE Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota

Table 2.1 Summary of DOE's Three-Step Process for Evaluating Radiation Doses to Aquatic and Terrestrial Biota

1. Data Assembly	Knowledge of sources, receptors, and routes of exposure for the area to be evaluated is summarized. Measured radionuclide concentrations in water, sediment, and soil are assembled for subsequent screening.
2. General Screening	Maximum measured radionuclide concentrations in an environmental medium (i.e., water, sediment, soil) are compared with a set of Biota Concentration Guides (BCGs). Each radionuclide-specific BCG represents the limiting radionuclide concentration in an environmental medium which would not result in recommended dose standards for biota to be exceeded.
3. Analysis	This phase consists of three increasingly more detailed steps of analysis.
(a) Site-Specific Screening	Site-specific screening, using more realistic site-representative lumped parameters (e.g., bioaccumulation factors) in place of conservative default parameters. Use of mean radionuclide concentrations in place of maximum values, taking into account time dependence and spatial extent of contamination, may be considered.
(b) Site-Specific Analysis	Site-specific analysis employing a kinetic modeling tool (applicable to riparian and terrestrial animal organism types) provided as part of the graded approach methodology. Multiple parameters which represent contributions to the organism's internal dose (e.g., body mass, consumption rate of food/soil, inhalation rate, lifespan, biological elimination rates) can be modified to represent site and organism-specific characteristics. The kinetic model employs allometric equations relating body mass to these internal dose parameters.
(c) Site-Specific Biota Dose Assessment	An actual site-specific biota dose assessment involving the collection and analysis of biota samples. The dose assessment would involve a problem formulation, analysis, and risk characterization protocol consistent with the widely-used ecological risk assessment paradigm.

2.1 Key Features of the Graded Approach

The graded approach was designed for flexibility and acceptability:

- It provides users with a tiered approach for demonstrating compliance with biota dose limits that is generally cost-effective and easy-to-implement.

- It allows for the use of measured radionuclide concentrations in environmental media typically collected as part of routine environmental surveillance programs.

- It is designed for multiple applications. The technical standard is applicable to demonstrations of compliance with biota dose limits and for use in ecological risk assessments of radiological impact.

- It provides a framework that supports the use of site-specific information.

- It incorporates ecological risk assessment concepts and provides guidance for site-specific biota dose assessments (where needed) employing the widely-used ecological risk assessment (ERA) paradigm.

- All of the equations and resulting BCGs contained in this technical standard have been encoded into a series of electronic spreadsheets. The spreadsheets were built using Microsoft Excel® and incorporate Visual Basic® commands to help guide and automate the user's progression through the biota dose evaluation process. Use of these spreadsheets, termed the "RAD-BCG Calculator," is described in Module 1, Sections 4-8. Refer to Module 1, Section 4 for an overview of the RAD-BCG Calculator and its contents for use as a companion tool to this technical standard.

- It provides users with "a place to start" and "an analysis path forward." The BCGs are not stand-alone. Exceedance of BCGs leads the user to the more-detailed tiers of analysis as needed in a stepwise manner. These linkages are an integral part of the graded approach framework and are built into the companion software tool, the RAD-BCG Calculator.

2.2 Key Points Regarding Methods Derivation

Internal and external sources of dose (and their contributing exposure pathways) are incorporated in the derivation of the graded approach methodology. Sufficient prudence has been exercised in the development of each of the assumptions and default parameter values to ensure that the resulting BCGs are appropriately conservative. In the event that an individual default parameter value is subsequently found to be an upper-end value but not the "most limiting" value for a unique site-specific exposure scenario, the other prudent assumptions and default parameter values will ensure that the BCGs (and resultant doses to biota) should continue to carry the appropriate degree of conservatism for screening purposes. Refer to Module 3 for a detailed description of the derivation of dose equations and default parameters used in the graded approach. Key assumptions used in deriving the BCGs that highlight the conservatism applied in the general screening phase are presented in Table 2.2. Exposure pathways for each of the reference organism types considered in the graded approach are presented in Figures 2.2 through 2.5. A summary of the general dose equation and approach used to derive the BCGs is provided in Table 2.3.

Table 2.2 Assumptions Regarding Sources, Receptors, and Routes of Exposure Applied in the General Screening Phase of the Graded Approach

Dose Limits	• BCGs were derived for aquatic animal, riparian animal, terrestrial plant, and terrestrial animal reference organisms. The dose rate limits used to derive the BCGs for each organism type are 1 rad/d, 0.1 rad/d, 1 rad/d, and 0.1 rad/d respectively. • While existing effects data support the application of these dose limits to representative individuals within populations of plants and animals, the assumptions and parameters applied in the derivation of the BCGs are based on a maximally exposed individual, representing a conservative approach for screening purposes.
External Sources of Radiation Exposure	• Estimates of the contribution to dose from external radioactive material were made assuming that all of the ionizing radiation was deposited in the organism (i.e., no pass-through and no self-shielding). This is conservative, and is tantamount to assuming that the radiosensitive tissues of concern (the reproductive tissues) lie on the surface of a very small organism. • For external exposure to contaminated soil, the source was presumed to be infinite in extent. In the case of external exposure to contaminated sediment and water, the source was presumed to be semi-infinite in extent. • The source medium to which the organisms are continuously exposed is assumed to contain uniform concentrations of radionuclides. • These assumptions provide for appropriately conservative estimates of energy deposition in the organism from external sources of radiation exposure.
Internal Sources of Radiation Exposure	• Estimates of the contribution to dose from internal radioactive material were conservatively made assuming that all of the decay energy is retained in the tissue of the organism, (i.e., 100% absorption). • Progeny of radionuclides and their decay chains are also included. This provides an over-estimate of internal exposure, as the lifetime of many of the biota of interest is generally short compared to the time for the build-up of progeny for certain radionuclides. • The radionuclides are presumed to be homogeneously distributed in the tissues of the receptor organism. This is unlikely to under-estimate the actual dose to the tissues of concern (i.e., reproductive organs). • A radiation weighing factor of 20 for alpha particles is used in calculating the BCGs for all organism types. This is conservative, especially if non-stochastic effects are most important in determining harm to biota. The true value may be a factor of 3 to 4 lower.

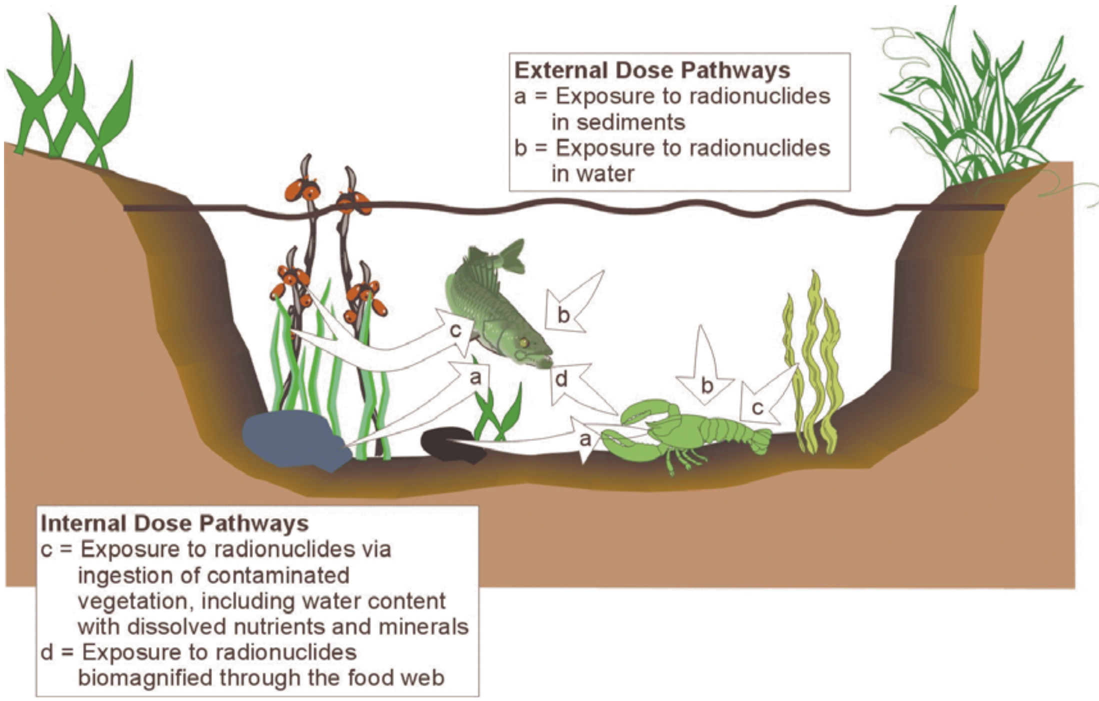


Figure 2.2 Exposure Pathways for Aquatic Animals

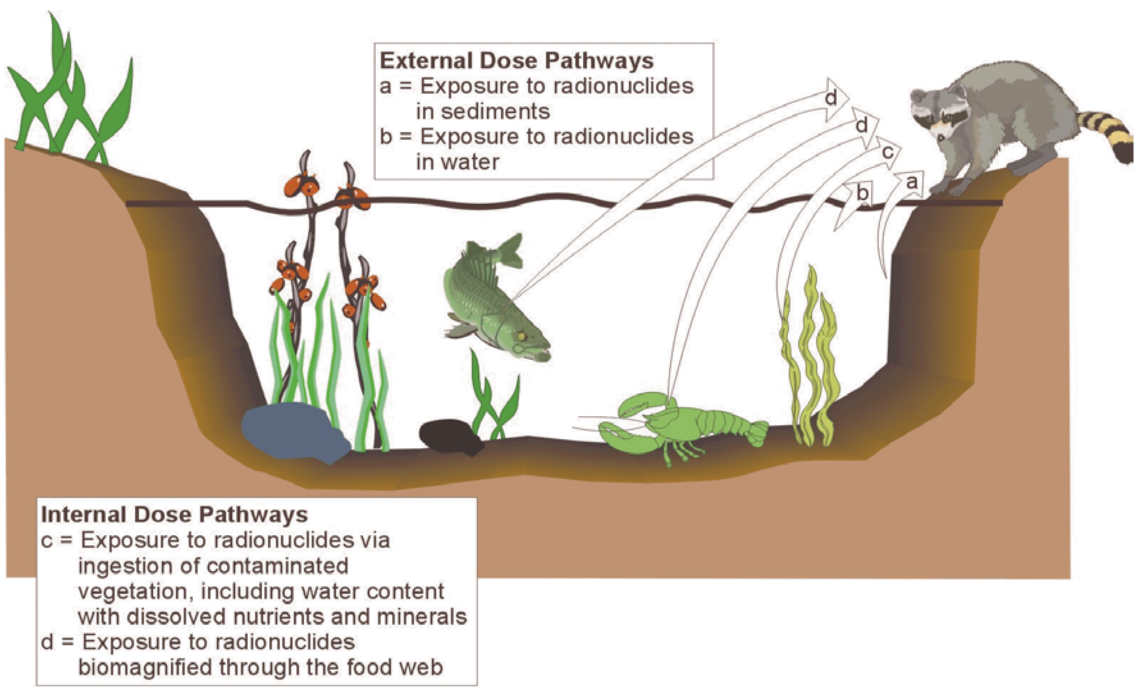


Figure 2.3 Exposure Pathways for Riparian Animals

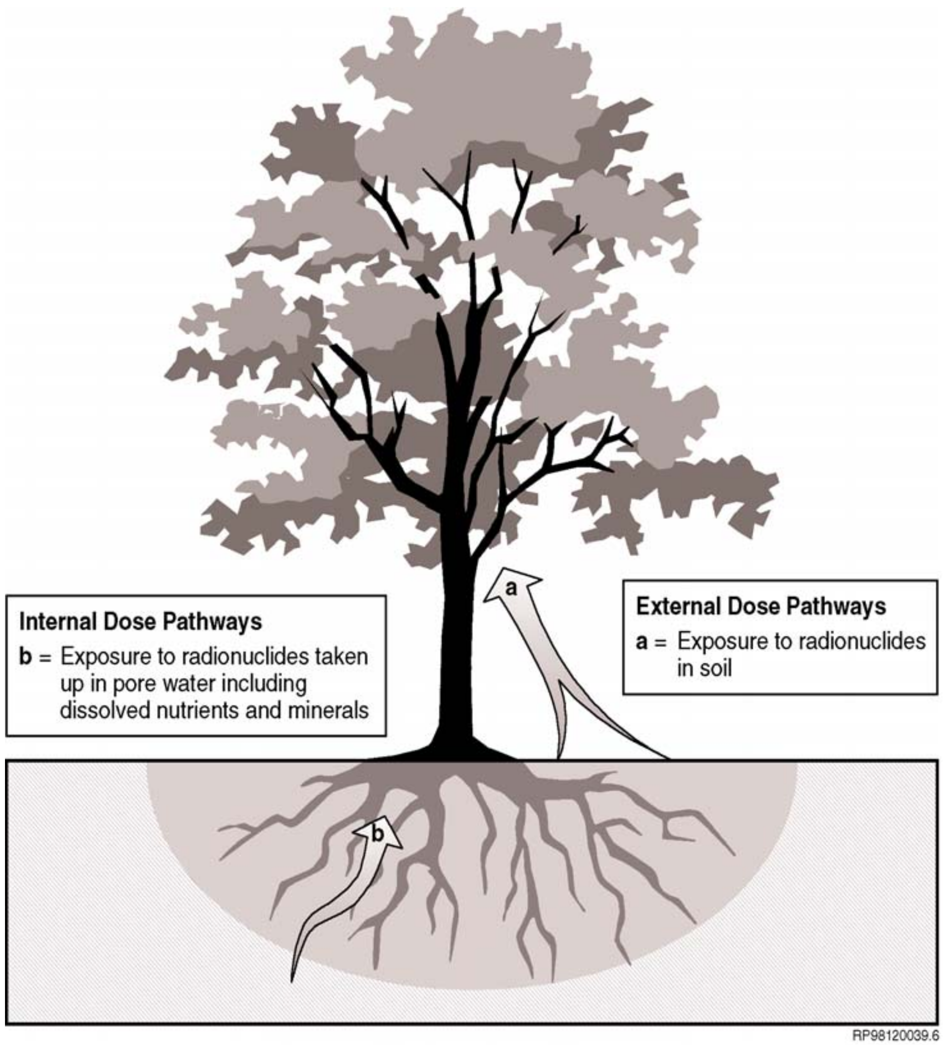


Figure 2.4 Exposure Pathways for Terrestrial Plants

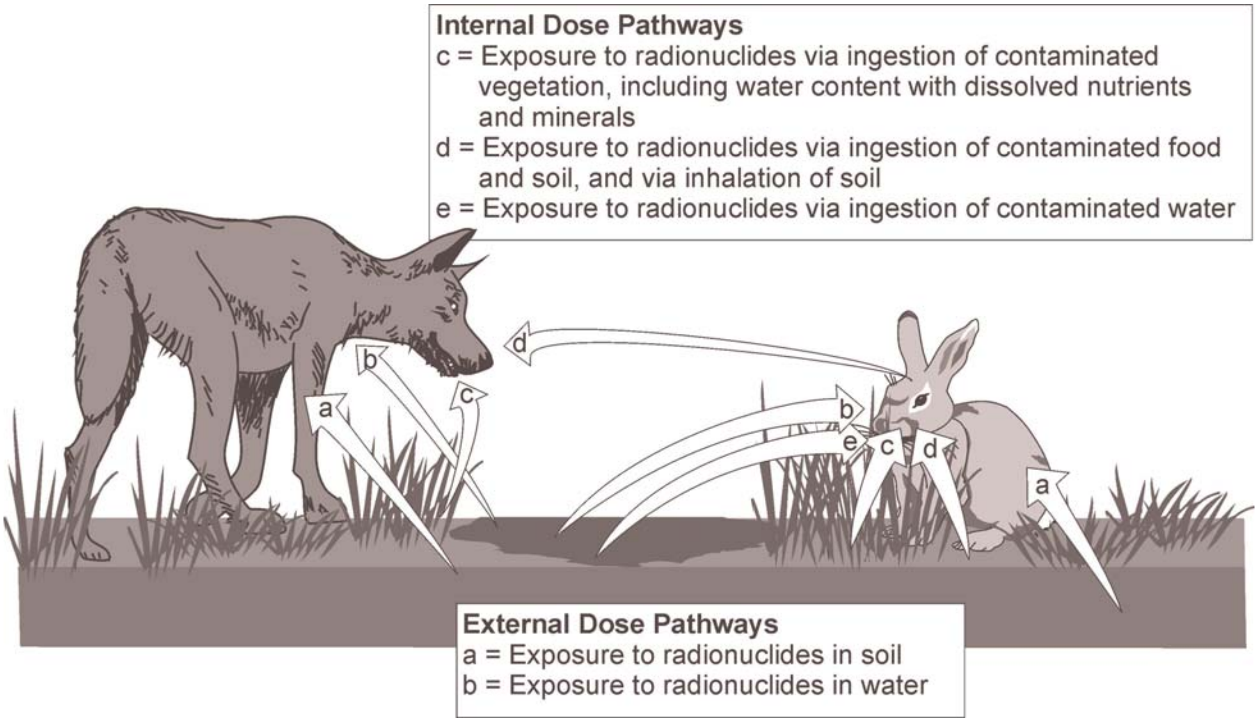


Figure 2.5 Exposure Pathways for Terrestrial Animals

Table 2.3 General Dose Equation and Approach Used to Derive BCGs

$$\text{Limiting Concentration} = \frac{\text{Dose Rate Limit}}{(\text{Internal Dose Rate}) + (\text{External Dose Rate}_{\text{soil/sed.}}) + (\text{External Dose Rate}_{\text{water}})}$$
• The limiting concentration in an environmental medium was calculated by first setting a target total dose (e.g., 1 rad/d for aquatic organisms and terrestrial plants, or 0.1 rad/d for riparian and terrestrial animals) and then back-calculating to the medium concentration (i.e., the BCG) necessary to produce the applicable dose from radionuclides in the organism (internal dose), plus the external dose components from radionuclides in the environment (external dose). • The denominator of the generic equation represents the dose per unit media concentration and may be broken down into the base components of internal and external dose. • Internal doses originate from radionuclides inside the organism's body. The internal dose is calculated as the product of the internal radionuclide concentration and internal dose conversion factor. External doses originate from radionuclides external to the organism and are calculated as the product of the radionuclide concentration in the environmental medium in which the organism resides and an appropriate dose conversion factor.

2.3 Relationship of the Graded Approach to Ecological Risk Assessment

The Graded Approach Is a Framework for Organizing Successively Rigorous Tiers of Assessment, with a Particular Emphasis on Ionizing Radiation.

The graded approach for evaluating radiation doses to aquatic and terrestrial biota is consistent with the standard ecological risk assessment (ERA) paradigm (EPA 1998). As in the standard ERA paradigm, the graded approach moves from a simple and relatively conservative screening evaluation to a more detailed and realistic assessment. Each step in the graded approach addresses, either explicitly or implicitly, the principal ERA components. That is, the graded approach is a framework for organizing the successively rigorous ERA tiers, <u>but with a particular emphasis on ionizing radiation</u>.

The graded approach for evaluating radiation doses to aquatic and terrestrial biota is consistent with the standard ecological risk assessment (ERA) paradigm (EPA 1998). The ERA structure provides a process for organizing and evaluating information to determine the nature, likelihood, and magnitude of potential impacts on environmental receptors (Suter 1993). The three major phases of an ERA are problem formulation, analysis of exposure and effects, and risk characterization. The ERA is typically done in successively rigorous tiers, each of which includes the three general ERA phases (Suter, Efroymson, Sample & Jones 2000). As in the widely-used ERA paradigm, the graded approach moves from a simple and relatively conservative screening evaluation to a more detailed and realistic assessment. Each step in the graded approach addresses, either explicitly or implicitly, all of the aforementioned ERA components. That is, the graded approach is a framework for organizing the successively rigorous ERA tiers, but with a particular emphasis on ionizing radiation.

The ERA process is general in nature and could be applied to the evaluation of radiation as a stressor, but not without some modifications and provision of additional guidance. There are some noteworthy technical issues concerning the evaluation of radiation that require further consideration and elaboration. Some issues are the same as for chemicals, but some are unique to radionuclides. In response to requests for guidance on this topic, Module 2, Section 1 provides a basic “primer” on technical issues that should be considered when evaluating radiation as a stressor to the environment, and draws on the experiences gained by BDAC members in developing the graded approach and conducting radiological ERAs. To our knowledge, standardized guidance on how to address these issues is not available elsewhere.

3 Application Considerations

The principal application of the graded approach is to demonstrate that routine DOE operations and activities are in compliance with the biota dose limits for protecting populations of plants and animals. In addition, the design of the graded approach (e.g., assumptions used; a multi-tiered screening and analysis approach; flexibility to allow use of site-specific information on sources, receptors, and routes of exposure) permits its application in ecological assessments of radiological impact and in other environmental assessment scenarios. Discussions on other intended or potential applications of the graded approach were first held in 1999 at a Biota Dose Assessment Committee (BDAC) Meeting (DOE 1999). Additional applications of the graded approach were identified by users and reviewers of an interim version of this technical standard that was made available for a trial use period beginning in July 2000 (DOE 2000a). Recommendations made by BDAC members and users on the intended and potential applications of the graded approach are summarized in an applications matrix (Table 3.1).

Data Quality Objectives

Data quality objectives (DQOs) shall be considered when determining the appropriateness of applying the DOE graded approach to other environmental assessment scenarios identified in Table 3.1.

Table 3.1 Applications Matrix Summarizing Intended and Potential Uses of the DOE Graded Approach

APPLICATIONS	INTENDED / POTENTIAL USE	CONSIDERATIONS
Types of Receptors		
Populations of plants and animals	This is the primary intended use.	
Individual plants and animals, including threatened and endangered species, and commercially or culturally valued species	Equations used within the graded approach are technically sound for application to individual organisms. Applying dose limits intended for the protection of populations to evaluations of individuals may require further consideration.	Use of effects endpoints/dose limits appropriate for protection of the individuals being evaluated; and/or application of safety factors, conservative exposure assumptions, and parameter values. Dose evaluations should be performed under the provisions of the applicable Federal and/or state statutes or regulations for rare and endangered species.

Table 3.1 (Continued) Applications Matrix Summarizing Intended and Potential Uses of the DOE Graded Approach

APPLICATIONS	INTENDED / POTENTIAL USE	CONSIDERATIONS
Types of Exposure		
Chronic	The methodology assumes chronic exposure and equilibrium conditions.	
Acute		The methodology is not intended to be used for assessing acute exposures. The models and assumptions used in the graded approach assume equilibrium conditions.
Accidents	Could be used to provide an indication of long-term "recovery" or health of the population over time following an accident. Equations and models used within the graded approach are technically sound for this application.	Accidents typically result in short-term, acute exposures for which the methodology is not intended. However, it can be applied for assessing long-term exposures due to accidents.
Types of Environments		
Fresh water, coastal, and marine environments	The methodology is intended to be applied to fresh water environments, and can be applied to coastal and marine environments.	Care must be taken when selecting parameter values (e.g., receptor lumped parameters; K_d values), as fresh water, coastal, and marine equilibrium chemistry differ considerably.
Terrestrial environments	The methodology is intended to be applied to terrestrial environments.	
Compliance / Impact Assessment		
Demonstration that DOE activities are in compliance with biota dose limits	This is a principal DOE application of the graded approach.	

Table 3.1 (Continued) Applications Matrix Summarizing Intended and Potential Uses of the DOE Graded Approach

APPLICATIONS	INTENDED / POTENTIAL USE	CONSIDERATIONS
Compliance / Impact Assessment (Continued)		
National Environmental Policy Act (NEPA)	The graded approach could be coupled with predictive dispersion codes that model a facility's effluents prior to construction, to estimate doses to biota in the Environmental Impact Statement. C Comparison of alternatives C Screen for issues needing analysis C Defining significance criteria C Mitigation action plan	Effects and assessment endpoints selected for use in the biota dose evaluation should be relevant to the management goals of the study.
Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)	Screening for potential radiological impacts within an ecological risk assessment. C Remedial Investigation/ Feasibility Study (RI/FS) C Engineering Evaluation/ Cost Analysis (EE/CA)	Effects and assessment endpoints selected for use in the biota dose evaluation should be relevant to the management goals of the study.
Natural Resource Damage Assessments (NRDA)	Screening assessments.	Effects and assessment endpoints selected for use in the biota dose evaluation should be relevant to the management goals of the study.
Decommissioning	Could be used to evaluate doses to biota, and to predict future doses to biota, associated with pre- and post- site or facility decommissioning activities.	Effects and assessment endpoints selected for use in the biota dose evaluation should be relevant to the management goals of the study.
Resource Conservation and Recovery Act (RCRA)	C Mixing zone definition C Alternative concentration limits	Effects and assessment endpoints selected for use in the biota dose evaluation should be relevant to the management goals of the study.

Table 3.1 (Continued) Applications Matrix Summarizing Intended and Potential Uses of the DOE Graded Approach

APPLICATIONS	INTENDED / POTENTIAL USE	CONSIDERATIONS
Compliance / Impact Assessment (Continued)		
Clean Water Act	Mixing zone assessments.	Effects and assessment endpoints selected for use in the biota dose evaluation should be relevant to the management goals of the study.

As mentioned earlier, the principal driver and basis of need for developing the graded approach was to provide DOE field and program elements with methods for demonstrating compliance with DOE biota dose limits and recommendations for radiological protection of the environment. Thus, many of the decisions that are traditionally made when conducting a case-specific assessment (e.g., choice of indicator receptors; defining receptor exposure profiles; selection of effects endpoints) were made at a programmatic level and incorporated into the screening phase of the graded approach *a priori.* For example, the thresholds for adverse effects were set at the recommended limits for protection of natural populations of biota. Those are the appropriate effects levels for demonstrating protection with DOE requirements and recommendations for the protection of the environment from ionizing radiation (Module 1, Section 1.2). If the graded approach is used for other purposes (e.g., Table 3.1), then the programmatic objectives and the methods should be reviewed and discussed with the relevant decision makers and stakeholders, preferably via the Data Quality Objectives (DQO) process (Bilyard et al. 1997) to ensure that the results obtained through application of the graded approach will support the management goals and objectives of the environmental assessment.

3.1 Evaluating Doses to Individual Organisms

The equations and models used within the graded approach for estimating the dose per unit concentration of radionuclides in environmental media and for deriving the BCGs are also applicable to individual organisms. However, there are questions concerning the applicability of the biota dose limits to individual organisms. While the biota dose limits presented in Module 1, Section 1.1 were derived based on dose-response information for the most radiosensitive of all species studied, and taking into account the most radiosensitive life stages, the question of whether these dose limits can be applied to protection of individual members of a species, in contrast to protection of populations of species, requires further consideration. That is, for individual plants and animals, especially threatened and endangered species, the health effects of concern could be different from the effects of concern in protection of populations.

The application of safety factors to these dose limits is one approach that has been used in evaluating doses to individual organisms (e.g., for culturally valued species). Use of safety factors, appropriate default parameter values, maximum radionuclide concentrations in environmental media, and 100 percent organism residence time and exposure are factors to consider in the application of the graded approach for evaluating doses to individuals. Refer to Module 2, Section 8 for a more detailed discussion on this issue. Specific cases where evaluation of individual organisms may be needed are discussed below.

3.1.1 Threatened and Endangered Species

Care must be taken by the user if the graded approach is applied in an evaluation of potential radiological impacts to endangered, threatened, rare, or otherwise sensitive species of plants and animals managed under the Federal Endangered Species Act or similar state laws or regulations pertaining to rare or endangered species (Endangered Species Act, 16 USC 1531 et seq.). It is the users responsibility to select effects and assessment endpoints, and the required input parameter values that reflect actual or expected exposure profiles, for the individuals being evaluated. Protection of endangered species should be performed under the provisions of the applicable Federal and/or state statutes or regulations for rare and endangered species.

3.1.2 Commercially and Culturally Valued Species

Care must be taken by the user if the graded approach is applied in an evaluation of potential radiological imacts to these categories of species. These would include species that are routinely harvested for their economic value (e.g., salmon) or their cultural value (e.g., medicinal plants used by Native Americans). One issue is whether or not these species should be evaluated at the individual or the population level. It is the users responsibility to select effects and assessment endpoints, and the required input parameter values that reflect actual or expected exposure profiles, for the individuals being evaluated.

3.2 Evaluating Doses to Aquatic Plants

Available information about the effects of ionizing radiation on aquatic plants does not appear to be adequate to characterize their sensitivity to ionizing radiation, or to establish defensible recommendations (i.e., in the form of dose standards or criteria) for allowable exposures of populations or individuals. However, regarding this technical standard, indirect means can provide a general qualitative indication of the effects to aquatic plants relative to effects on other organisms. In general, one would expect substantially lower radiosensitivity in higher plants in comparison to the most sensitive birds, fishes and mammals (Whicker and Schultz 1982; Whicker 1997). Therefore, an evaluation using this technical standard that demonstrates protection of aquatic and riparian animals should provide an indication that aquatic plants are also likely protected. Alternatively, appropriate bioaccumulation factors (B_{iv}s) for aquatic plants could be used in the appropriate aquatic system spreadsheets to calculate BCGs for aquatic plants. Refer to Module 2, Section 2.3, and Module 3, Section 3.2.1, for guidance in this area.

3.3 Experimental Facilities

The methods in this technical standard are not directly intended to be applied to properly permitted experimental facilities that expose biota to ionizing radiation without releasing materials to the environment (e.g., particle beam accelerators). Although the operation of such facilities may be considered to be "routine," any inadvertent exposure of biota as a result of such operations should have been addressed in the operating permit, precluding any need to apply the methods described herein. Additionally, any such exposures would be localized, and would thus be unlikely to affect substantial populations of any species that this technical standard addresses. Refer to Module 2, Section 2.4 for detailed considerations and methods for evaluating potential impacts to biota around accelerators or other sources of direct radiation.

3.4 Hazardous Chemicals and Industrial Hazards

The methods in this technical standard are not appropriate for evaluating potential impacts on biota from hazardous chemicals or industrial-type hazards, including noise and traffic.

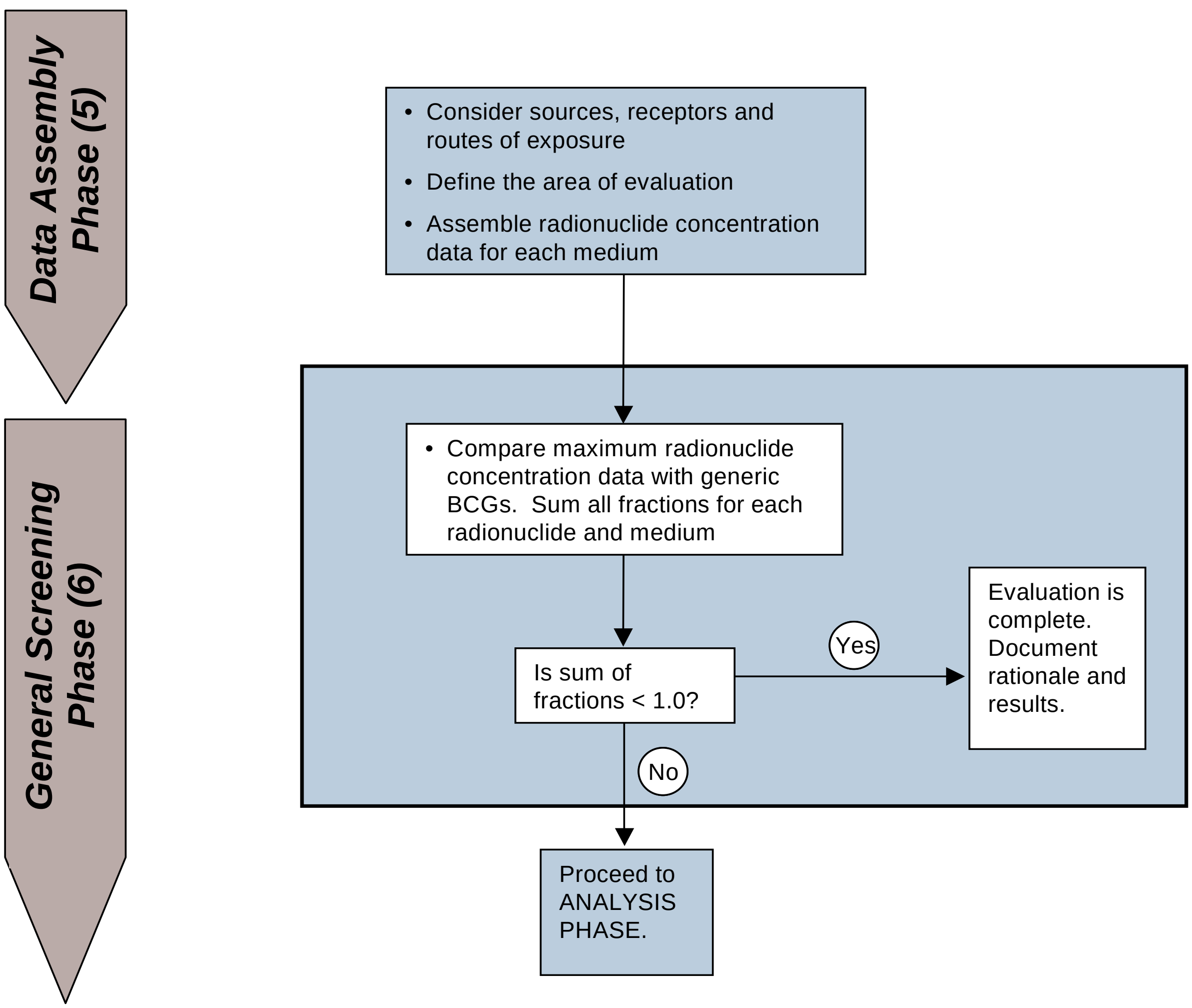
3.5 Frequency of Conducting Evaluations

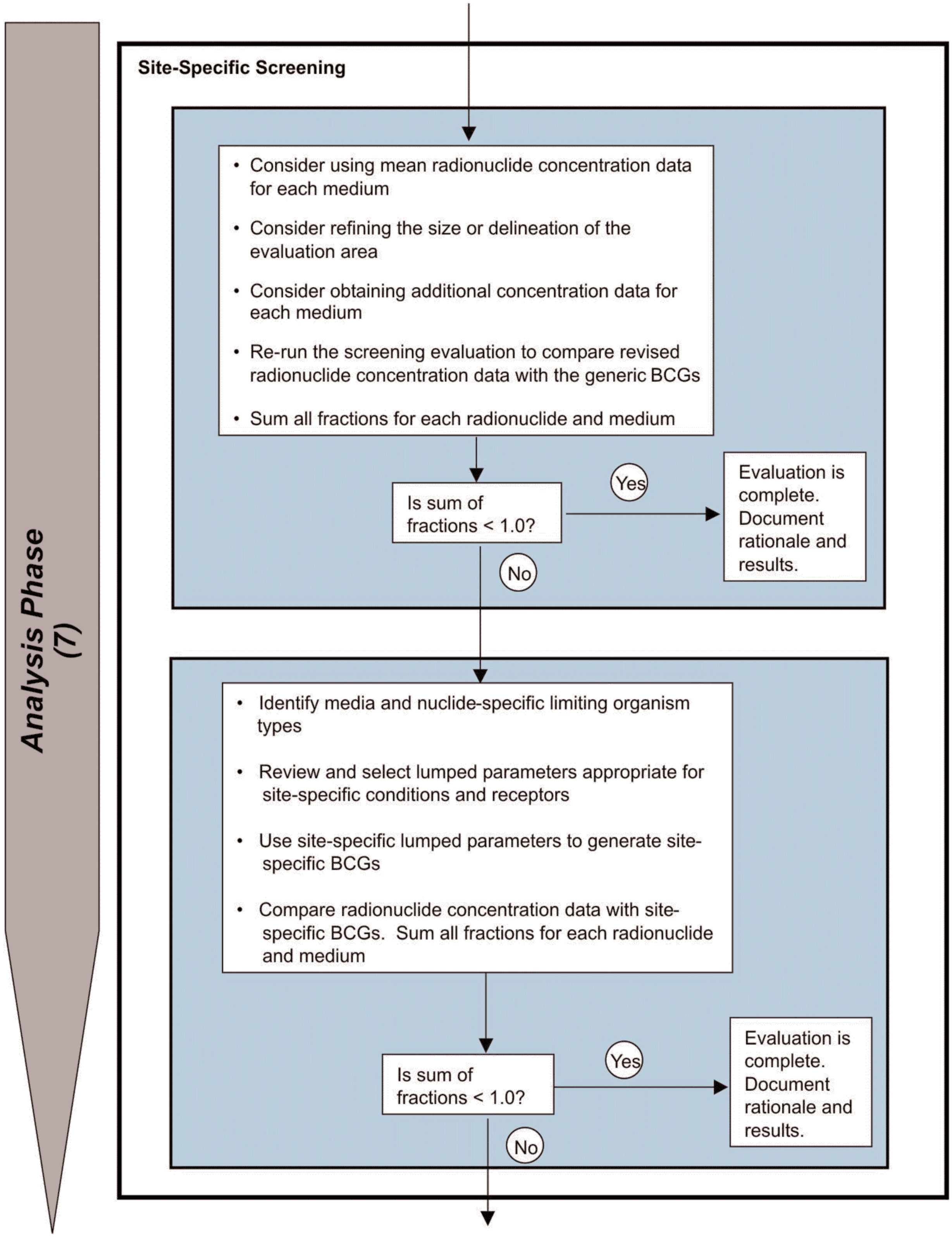
Dose evaluations for aquatic and terrestrial biota shall be conducted annually in conjunction with the preparation of annual site environmental reports that are required under DOE Orders 5400.1 and 5400.5. More frequent evaluations could be required at the direction of DOE's Office of Environment, Safety and Health (EH).

4 Step-by-Step Implementation of the Graded Approach

Here we present an overview of the complete process for implementing the graded approach. This section is provided to help orient you to the step-by-step guidance corresponding to each phase of the graded approach which follows in Sections 5 - 8 of this Module. A flowchart showing how to progress through each phase of the graded approach, and the components of each phase, is provided in Figure 4.1. Refer to this figure as you proceed through the step-by-step guidance presented in subsequent sections. References to more comprehensive guidance (presented in Module 2 of this technical standard) are provided throughout the step-by-step guidance. Example applications of the graded approach, using actual DOE site data, are presented in Section 9 of this Module.

Figure 4.1 Flowchart Illustrating Step-by-Step Guidance for Progressing Through the DOE Graded Approach. Section numbers within this technical standard corresponding to each phase are highlighted for reference.




Analysis Phase
(7)
Site-Specific Screening
• Consider using mean radionuclide concentration data for each medium
• Consider refining the size or delineation of the evaluation area
• Consider obtaining additional concentration data for each medium
• Re-run the screening evaluation to compare revised radionuclide concentration data with the generic BCGs
• Sum all fractions for each radionuclide and medium
Is sum of fractions < 1.0?
Yes
Evaluation is complete. Document rationale and results.
No
• Identify media and nuclide-specific limiting organism types
• Review and select lumped parameters appropriate for site-specific conditions and receptors
• Use site-specific lumped parameters to generate site-specific BCGs
• Compare radionuclide concentration data with site-specific BCGs. Sum all fractions for each radionuclide and medium
Is sum of fractions < 1.0?
Yes
Evaluation is complete. Document rationale and results.
No

Analysis Phase (7)

Site-Specific Analysis

- Identify media and nuclide-specific limiting organism types
- Consider correction factor for exposure area or receptor residence time
- For riparian and terrestrial animals, review and select parameters contributing to internal dose (e.g., body mass; ingestion and inhalation rates; biological decay and f_1 values) appropriate for site-specific receptors
- Use site-specific parameters to generate site-specific BCGs
- Compare radionuclide concentration data with site-specific BCGs. Sum all fractions for each radionuclide and medium

Is sum of fractions < 1.0?

Yes

Evaluation is complete. Document rationale and results.

No

Site-Specific Biota Dose Assessment

- Consider use of available biota tissue data
- Assemble a biota dose assessment team
- Review requirements and assumptions
- Design and conduct the biota dose assessment
    - Problem formulation
    - Analysis
    - Risk characterization

Document rationale and results.

4.1 Parameter Values that Can be Modified in the Graded Approach

DOE's three-phased approach is designed to guide you from an initial conservative evaluation using general screening to, if needed, a more rigorous analysis using site-specific information. The amount of effort required for your biota dose evaluation and the information needed on site-specific conditions and receptors increases as you progress through the three phases of the graded approach, particularly during the analysis phase. The result will be a set of less conservative, more realistic site-representative BCGs. Table 4.1 provides a general summary of parameter values that can be modified or applied corresponding to each phase of the graded approach. Use this table as a reference when progressing through the step-by-step guidance provided in subsequent sections of this Module.

Table 4.1 Summary of Parameter Values that Can, with Technical Justification, be Modified Corresponding to Each Phase of the Graded Approach

Phase	Parameters[1]
Data Assembly	• Size of evaluation area • Radionuclide concentrations in environmental media
General Screening	• Initial general screening using maximum radionuclide concentrations: No parameter modifications are allowed
Analysis: *Site-Specific Screening*	• Use of mean radionuclide concentrations, taking into account time dependence and spatial extent of contamination, may be considered • Site-specific lumped parameter values in place of default values used in the general screening phase • Sediment K_d values may be modified, with technical justification, for aquatic system evaluations where only water or only sediment concentration data are available for the screening process
Site-Specific Analysis	• A correction factor for exposure area or receptor residence time for all organism types may be considered • For riparian and terrestrial animals: - Food source B_{iv} value for riparian and terrestrial animals - Body mass - Uptake fraction of radionuclide ingested/absorbed (f_1) - Biological elimination rate constant of radionuclide exiting the organism (λ_{bio})

Table 4.1 (Continued) Summary of Parameter Values that Can, with Technical Justification, be Modified Corresponding to Each Phase of the Graded Approach

Phase	Parameters[1]
	- Food intake rate and supporting parameters - Soil intake rate and supporting parameters - Inhalation rate and supporting parameters - Soil inhalation rate and supporting parameters - Water consumption rate - Maximum life span - Allometric equations provided can be modified
Site-Specific Biota Dose Assessment	• Design, collection, and direct analysis of environmental media and biota

[1] The RAD-BCG Calculator provides the capabilities to modify the dose limits for aquatic and terrestrial organisms, to modify the RBE weighting factor for alpha emitters, and to de-select inclusion of energies for progeny of chain-decaying nuclides with regard to internal dose conversion factors. These default values shall be used in dose evaluations conducted for DOE sites. See Module 2, Section 7 for a detailed discussion on the selection of the RBE weighting factor for alpha emitters.

4.2 Use of the RAD-BCG Calculator

The RAD-BCG Calculator is a companion tool to the technical standard. It contains a series of electronic spreadsheets for use in:

- entering site data on radionuclide concentrations in soil, sediment, or water,
- comparing radionuclide-specific data with radionuclide-specific BCGs,
- determining if the sum of fractions for all radionuclide data/BCG comparisons is less than 1.0, and
- when technically justified, modifiying default parameters used in the general screening phase, and calculating site-specific BCGs using site-specific information representing the evaluation area and receptors.

A Table of Contents within the RAD-BCG Calculator provides a listing of the spreadsheets and information text screens, with a brief statement about their application. The contents of the RAD-BCG Calculator are also provided in Table 4.2.

Within these electronic spreadsheets, several fields (e.g., columns) of cells contain notes, viewed by placing the cursor over the cell, that provide additional information on the source of the number of parameter value cited in that cell. The equations used to derive the BCG calculations and to link values across different spreadsheets are presented in a separate protected spreadsheet within the RAD-BCG Calculator. The equations and assumptions used to derive the BCGs are described in detail within Module 3 of this technical standard.

4.3 The Biota Dose Assessment Committee

The Biota Dose Assessment Committee (BDAC), chaired by DOE's Air, Water and Radiation Division (EH-412), is available as a resource to answer questions concerning the graded approach for evaluating radiation doses to biota. The BDAC is an approved technical standards topical committee organized under the DOE Technical Standards Program. As stated in its charter, the purpose of the BDAC is (a) to assist, consistent with DOE needs, in developing and promoting technical standards and associated guidance for DOE-wide applications in assessing radiation dose to biota, (b) to serve as a major forum within DOE for obtaining technical assistance, discussing technical issues, and sharing lessons learned regarding biota dose standards and assessment methods, and (c) to serve as a technical resource and advisory group for DOE program and field elements regarding site-specific biota dose assessments. The BDAC web site (http://homer.ornl.gov/oepa/public/bdac) provides internet access to guidance, methods, and related tools associated with this technical standard; links to related web sites also are provided. Specific questions concerning the guidance and methods contained in this technical standard, and requests for consultation with the BDAC Core Team, should be coordinated through EH-412 (contact Stephen Domotor, 202-586-0871, Stephen.Domotor@eh.doe.gov).

The BDAC is available as a resource to DOE program and field elements

The Department's Biota Dose Assessment Committee is available as a technical resource and advisory group concerning evaluation of radiation doses to biota. Questions concerning the application of the DOE graded approach should be coordinated through DOE's Air, Water and Radiation Division (EH-412).

Table 4.2 Contents of the RAD-BCG Calculator. A listing of the spreadsheets and information text screens, with a brief statement on their application and relationship to tables contained in this technical standard, is provided.

Spreadsheet Type	Spreadsheet Title	Content Description	Parameters That Can Be Modified
Information Text Screens	Front Page	Welcoming comments and a description of the purpose of the RAD-BCG Calculator, and its intended use. Provides a link to begin a semi-automated biota dose evaluation using the RAD-BCG Calculator.	
	Overview	Provides an overview of DOE's graded approach for evaluating radiation doses to aquatic and terrestrial biota. Summarizes the three phases (data assembly, general screening, analysis) of the graded approach. Provides a link to begin a semi-automated biota dose evaluation using the RAD-BCG Calculator.	
	Table of Contents	Lists all spreadsheets and information text screens included in the RAD-BCG Calculator.	
	Getting Started	Provides general considerations on the general site information required for defining the evaluation area and conducting a biota dose evaluation using the screening methods contained in the technical standard, along with general considerations when conducting an aquatic vs. terrestrial system evaluation. Provides a link for continuing on with a semi-automated evaluation.	
Principal Screening and Analysis Spreadsheets	Initial Conditions	Allows the user to select SI (e.g., Bq/kg) or special (e.g., pCi/g) units in the biota dose evaluation. Provides a feature to reset all parameters to their default values.	Restore initial default parameters; select units
	Aquatic and Terrestrial System Data Entry/BCG Worksheets	Provides the environmental system data entry/BCG worksheet for aquatic system evaluations and terrestrial system evaluations, respectively. Allows the user to enter data on radionuclide concentrations in soil, sediment and water. Lists the BCGs for each radionuclide. Calculates the sum of fractions for all radionuclide data/BCG comparisons and indicates if this sum of fractions is less than 1.0. Lists the limiting organism type responsible for the BCG cited, which references the organism type spreadsheet where default parameters can be modified with site-specific values.	Site radionuclide concentration data for soil, sediment, and water

Spreadsheet Type	Spreadsheet Title	Content Description	Parameters That Can Be Modified
Supporting Parameter and Reference Spreadsheets	Aquatic Animal	Contains the basic parameters used in the calculation of water and sediment BCGs for aquatic biota. Contains all of the same information and parameters as is presented in Module 1, Table 7.1.	B_{iv}; correction factor for exposure area and time
	Terrestrial Plant	Contains the basic parameters used in the calculation of water and soil BCGs for terrestrial plants. Contains all of the same information and parameters as is presented in Module 1, Table 7.3.	B_{iv}; correction factor for exposure area and time
	Riparian Animal	Contains the basic parameters used in the calculation of water and sediment BCGs for riparian animals. Contains all of the same information and parameters as is presented in Module 1, Tables 7.2, 7.5, and 7.6.	With "lumped BCGs" selected: lumped parameter; correction factors for exposure area and time; with "allometric BCGs" selected: correction factors for exposure area and time; fraction of intake retained; biological decay constant; all allometric parameters and equations
	Terrestrial Animal	Contains the basic parameters used in the calculation of water and soil BCGs for terrestrial animals. Contains all of the same information and parameters as is presented in Module 1, Tables 7.4, 7.7, and 7.8.	With "lumped BCGs" selected: lumped parameter; correction factors for exposure area and time; with "allometric BCGs" selected: correction factors for exposure area and time; fraction of intake retained; biological decay constant; all allometric parameters and equations
Supporting Spreadsheets	Dose Factors and Common Parameters	Contains internal dose conversion factors, and external dose conversion factors in soil, sediment and water for each radionuclide. Contains sediment and soil most probable K_d values used as default parameters, and provides their ranges. Contains all of the same information and parameters as is presented in Module 1, Tables 6.5 and 7.9.	Most probable K_d values; radiation weighting factor for alpha emitters; inclusion of energies for progeny of chain-decaying nuclides with regard to internal dose conversion factors
	Decay Chains	Contains decay chains (both with and without progeny) for each radionuclide. This spreadsheet is not provided in the technical standard.	

5 Data Assembly Phase

The DOE graded approach for evaluating radiation doses to aquatic and terrestrial biota was designed to minimize the need for additional data collection above and beyond environmental radionuclide concentration data typically available through routine environmental monitoring and surveillance programs. The data assembly phase encompasses three steps: (1) considering the sources of radioactivity, the key receptors, and the routes of exposure to these receptors; (2) defining the geographic area to be evaluated; and (3) assembling and organizing data on radionuclide concentrations in water, sediments, and soil for use in the general screening phase, and for use in the analysis phase, if needed. Each of the three steps are interdependent and should be considered collectively when implementing the data assembly phase.

5.1 Step 1: Consider the Sources, Receptors, and Routes of Exposure

It is expected that general knowledge concerning sources, receptors, and routes of exposure will be sufficient for defining the geographic area of evaluation when implementing the general screening phase of the graded approach. However, more detailed information regarding these elements may need to be considered as you progress through the graded approach. For example, if the BCGs for the general screening evaluation are exceeded, you may wish to refine your input data for site-specific screening (e.g., using mean radionuclide concentration data in place of maximum values; re-defining the geographic area of evaluation). Alternatively, you may wish to move to the site-specific analysis component of the graded approach, which may require consideration of internal dose parameters relating to site-specific receptors and routes of exposure. Detailed guidance on consideration of sources, receptors, and routes of exposure, for application in defining the area of evaluation and for use in the analysis phase, is provided in Module 2, Section 2.

5.2 Step 2: Define Your Area of Evaluation

It is necessary to determine the spatial extent over which the graded approach will be applied. The assumptions regarding sources, receptors, and routes of exposure used in the development of the graded approach provide for conservative BCGs. In the derivation of the screening approach, the source medium to which the organisms are exposed is assumed to be infinite in extent and to contain uniform concentrations of radionuclides. The organisms are also assumed to be resident in the contaminated area (e.g., exposed to contaminated media) 100 percent of the time. Given these

Three conditions should be present for a dose evaluation:

- *<u>Radioactivity</u> should be present or anticipated to be present in the environment as a result of DOE activities*
- *<u>Receptors</u> (i.e., plants and/or animals) should be present in the vicinity of those sources*
- *<u>Routes of exposure</u> should exist from those sources to the receptors*

assumptions, the first approach shall be to use maximum radionuclide concentration data applicable to your geographic area of interest (e.g., the entire site). A review of your effluent monitoring and environmental surveillance program design and resultant data should provide insights on sampling locations yielding the highest radionuclide concentrations.

5.3 Step 3: Assemble and Organize Data on Radionuclide Concentrations in Environmental Media

The next step is to collect and organize relevant data on radionuclide concentrations in environmental media. Radionuclide concentrations in surface water and/or sediment and in soil are needed for implementing the graded approach. Acceptable sources of data include but are not limited to: Annual Site Environmental Reports, effluent monitoring and environmental surveillance data, remediation data, and data from special site-specific studies (e.g., ecological studies conducted for other purposes). The data should be organized by location and medium, and be applicable to the geographic area of evaluation identified in Step 2 above. Locations may be defined by management and administrative characteristics (e.g., remediation sites; operations areas; operable units), physical characteristics (e.g., watershed; pond; stream), or ecological characteristics (e.g., corresponding to habitat types). Maximum radionuclide concentrations in environmental media shall be used in the initial application of the general screening phase to provide the most conservative evaluation.

5.3.1 Aquatic System Considerations

If you are conducting an aquatic system evaluation, note that use of radionuclide concentration data from co-located surface water and sediment samples is preferred and will result in a less conservative, more realistic evaluation. A mix of data from water and/or sediment samples collected from different locations within the vicinity of one another may be used, with justification. Note that where co-located samples are not available, only water or only sediment data may be used, but will result in a significantly more conservative evaluation. This is because the BCGs derived using individual water or sediment values involve the use of a conservative sediment distribution coefficient (K_d) to calculate the environmental media radionuclide concentration and dose contribution of either the missing water or sediment component.

5.3.2 Terrestrial System Considerations

If you are conducting a terrestrial system evaluation, you should consider the types of receptors resident in your area of evaluation and the appropriateness of your soil samples with regard to these receptors. For example, surface soil samples may not be representative of potential radionuclide exposure to deep-rooted plant receptors. Refer to Module 2, Section 5 for detailed guidance in this area. Also note that if you have a water body in your evaluation area, you must also conduct an aquatic system evaluation.

6 General Screening Phase

A major goal of the general screening phase is to provide a method that allows you to easily apply data on radionuclide concentrations in an environmental medium to evaluate compliance with the dose limits for biota. In the general screening phase, data on radionuclide concentrations in environmental media are compared with a set of generic BCGs. Each radionuclide-specific BCG represents the limiting radionuclide concentration in environmental media which would not result in DOE's established or recommended dose limits for biota to be exceeded. These limiting radionuclide concentrations, or BCGs, are presented in Tables 6.1 through 6.4. These "look-up" tables allow for quick, easy comparisons of radionuclide concentrations in environmental media with the BCGs. Guidance on using these look-up tables is provided below.

6.1 Step 1: Compare Data on Radionuclide Concentrations in Environmental Media with Generic BCGs Contained in Look-up Tables

A sum of fractions approach is used in comparing data on measured radionuclide concentrations in environmental media with the BCGs contained in the look-up tables. That is, when multiple radionuclides are present in multiple environmental media, the sum of fractions rule shall be applied to account for all sources of exposure. Hence, the sum of the ratios of the measured concentration of each radionuclide to its corresponding BCG for each medium shall then be summed across media, and the total sum of fractions shall not exceed 1.0.

Sum of Fractions Rule

When multiple radionuclides are present in multiple environmental media, the sum of fractions rule shall be applied to account for all sources of exposure.

For each environmental medium, for radionuclides A, B, ... N, with concentrations C_A, C_B ...C_N, and corresponding screening BCG values BCG_A, BCG_B, ... BCG_N, this relationship for aquatic and terrestrial system evaluations is as follows:

- Aquatic System Evaluation:

$$\left[\frac{C_A}{BCG_A} \% \frac{C_B}{BCG_B} \%...\% \frac{C_N}{BCG_N}\right] \text{water} \% \left[\frac{C_A}{BCG_A} \% \frac{C_B}{BCG_B} \%...\% \frac{C_N}{BCG_N}\right] \text{sediment} < 1.0$$

- Terrestrial System Evaluation:

$$\left[\frac{C_A}{BCG_A} \% \frac{C_B}{BCG_B} \%...\% \frac{C_N}{BCG_N}\right] \text{water} \% \left[\frac{C_A}{BCG_A} \% \frac{C_B}{BCG_B} \%...\% \frac{C_N}{BCG_N}\right] \text{soil} < 1.0$$

If the sum of fractions (the summed ratios between the radionuclide concentrations in environmental media and the radionuclide-specific BCGs) is less than 1.0, the dose to an aquatic or terrestrial receptor is below the biota dose limit, and you have passed the general screening evaluation. Proceed to Section 8, Documenting Your Biota Dose Evaluation Results. If the sum is greater than 1.0, further investigation is required (e.g., initiating site-specific screening or analysis).

Getting Started with the RAD-BCG Calculator

<u>Enable Macros.</u> Click on "Enable Macros" when prompted.

<u>Select your units.</u> You may work in either SI Units (e.g., Bq/kg) or Special Units (e.g., pCi/g). Select your units in the "Initial Conditions" spreadsheet of the RAD-BCG calculator.

<u>Enter your data.</u> The RAD-BCG Calculator contains aquatic and terrestrial system data entry/BCG worksheets. These environmental data/BCG worksheets allow you to enter your data on radionuclide concentrations in environmental media, automatically calculate the sum of fractions, and determine whether the sum of fractions is greater or less than 1.0.

When entering data for an aquatic system evaluation, be sure to select "water," "sediment," or "both," corresponding to the data you are working with.

The terrestrial system data entry/BCG worksheet provides a feature that allows you to import water data used in the aquatic evaluation, as appropriate.

<u>Prepare for General Screening.</u> To prepare for general screening, be sure that the "lumped BCGs" button is selected within the riparian and terrestrial animal spreadsheets.

Using the Sum of Fractions Rule: Terrestrial System Evaluation

Maximum radionuclide concentrations for water and soil collected within the evaluation area and available through the existing site environmental surveillance program were summarized. Maximum radionuclide concentrations for Cs-137 and Sr-90 in soil were 1.21 and 1.30 pCi/g, respectively. Maximum radionuclide concentrations for Cs-137 and Sr-90 in water were 49.6 and 84.5 pCi/L, respectively. Applying the sum of fractions rule, and using the BCG values listed in Table 6.4, one obtains the following:

soil: $\frac{1.21}{20} + \frac{1.30}{20} = 1.2E{-}01$

water: $\frac{49.6}{6E{+}05} + \frac{84.5}{5E{+}04} = 1.63E{-}03$

1.2E-01	+	1.77E-03	=	0.12
(soil sum of fractions)		(water sum of fractions)		(total sum of fractions)

Conclusion: Because 0.12 is less than 1.0, the dose to a terrestrial receptor does not exceed the recommended dose limits for protection of populations of terrestrial plants and animals. Note that the soil medium provides most of the contribution to dose.

Using the Sum of Fractions Rule: Aquatic System Evaluation

Maximum radionuclide concentrations for co-located water and sediment samples collected within the evaluation area and available through the existing site environmental surveillance program were summarized. Maximum radionuclide concentrations for water and sediment are:

	Sr-90	Cs-137
water (pCi/L)	1.5E-03	ND
sediment (pCi/g)	3.8	7.9

Applying the sum of fractions rule, and using the BCG values listed in Table 6.2, one obtains the following:

$$\frac{1.5E-03}{3E+02} + \frac{0}{4E+01} = 5.0E-06$$ (sum of fractions for radionuclides in water)

$$\frac{3.8}{6E+02} + \frac{7.9}{3E+03} = 8.96E-03$$ (sum of fractions for radionuclides in sediment)

$$5.0E-06 + 8.96E-03 = 8.96E-03$$ (total sum of fractions for radionuclides in water and sediment)

Conclusion: Dose to an aquatic receptor does not exceed the recommended dose limits for aquatic or riparian animals.

6.1.1 Aquatic System Considerations

In situations where co-located water and sediment data are not available, in the general screening phase you must estimate the missing radionuclide concentration data through the use of "most probable" radionuclide-specific K_d values. Radionuclide-specific most probable K_d values are provided in Table 6.5 of this Module and in the Dose Factors and Common Parameters spreadsheet of the RAD-BCG Calculator. The radionuclide concentration data estimated for the missing water or sediment medium is then used along

Estimating Radionuclide Concentration Data in Situations where Co-Located Water and Sediment Data are not Available

The RAD-BCG Calculator uses a "most probable" default K_d value to automatically calculate the missing radionuclide concentration, and then automatically enters it into the aquatic system data entry/BCG worksheet.

with the radionuclide concentration data for the available medium in the sum of fractions calculation as described previously.

Judgement should be applied in determining if measured radionuclide concentration data for water and sediment media can be considered as originating from co-located water and sediment samples. If measured radionuclide concentration data for water and sediment media are only available from separate locations, you should calculate the missing radionuclide concentration data for each missing medium, and apply the approach that results in the highest (e.g., most conservative) sum of fractions in your biota dose evaluation. Equations for estimating radionuclide concentration data in situations where co-located water and sediment data are not available are provided in Module 3, Section 3.2.3. If the sum of fractions is less than 1.0, the dose to an aquatic receptor is below the biota dose limit, and you have passed the general screening evaluation. Proceed to Section 8, Documenting Your Biota Dose Evaluation Results. If the sum is greater than 1.0, further investigation is required (e.g., initiating site-specific screening or analysis).

6.1.2 Dealing with High Background Levels of Naturally Occurring Radionuclides

Radiation dose rates at local background reference sites can be used to ensure that the site-related dose rates represent an actual increase in exposure. If the evaluation area is suspected or has been documented to have high background levels of naturally occurring radionuclides, these background levels may be taken into account when determining compliance of DOE activities with the biota dose limits. For example, this may be a consideration for the two isotopes of radium (see BCGs for Ra-226 and Ra-228, Tables 6.1 - 6.4). Background levels for environmental media should be estimated based on data for the same or similar media types in uncontaminated areas. If the sum of fractions for measured radionuclide concentrations in media from the contaminated area exceeds 1.0, this sum should be compared with the sum of fractions calculated using measured radionuclide concentrations in media from the background area. If the sum of fractions from the contaminated area does not exceed that from the background area, the contaminated area has passed the screening evaluation. Proceed to Module 1, Section 8 and document the results of the comparison. If it does exceed the background sum of fractions, proceed to the next phases of the graded approach. Refer to Module 2, Section 3.3.1, and Module 2, Section 6.3.1.5 for related guidance on this topic.

Table 6.1 Biota Concentration Guides (BCGs) for Water and Sediment (in SI Units) for Use in Aquatic System Evaluations. For use with radionuclide concentrations from co-located water and sediment.

Nuclide	BCG (water), Bq/m^3	Organism Responsible for Limiting Dose in Water	BCG (sediment), Bq/kg	Organism Responsible for Limiting Dose in Sediment
^{241}Am	2E+04	Aquatic Animal	2E+05	Riparian Animal
^{144}Ce	6E+04	Aquatic Animal	1E+05	Riparian Animal
^{135}Cs	2E+04	Riparian Animal	2E+06	Riparian Animal
^{137}Cs	2E+03	Riparian Animal	1E+05	Riparian Animal
^{60}Co	1E+05	Aquatic Animal	5E+04	Riparian Animal
^{154}Eu	8E+05	Aquatic Animal	1E+05	Riparian Animal
^{155}Eu	1E+07	Aquatic Animal	1E+06	Riparian Animal
^{3}H	1E+10	Riparian Animal	1E+07	Riparian Animal
^{129}I	1E+06	Riparian Animal	1E+06	Riparian Animal
^{131}I	5E+05	Riparian Animal	2E+05	Riparian Animal
^{239}Pu	7E+03	Aquatic Animal	2E+05	Riparian Animal
^{226}Ra	2E+02	Riparian Animal	4E+03	Riparian Animal
^{228}Ra	1E+02	Riparian Animal	3E+03	Riparian Animal
^{125}Sb	1E+07	Aquatic Animal	3E+05	Riparian Animal
^{90}Sr	1E+04	Riparian Animal	2E+04	Riparian Animal
^{99}Tc	2E+07	Riparian Animal	2E+06	Riparian Animal
^{232}Th	1E+04	Aquatic Animal	5E+04	Riparian Animal
^{233}U	7E+03	Aquatic Animal	2E+05	Riparian Animal
^{234}U	7E+03	Aquatic Animal	2E+05	Riparian Animal
^{235}U	8E+03	Aquatic Animal	1E+05	Riparian Animal
^{238}U	8E+03	Aquatic Animal	9E+04	Riparian Animal
^{65}Zn	5E+02	Riparian Animal	5E+04	Riparian Animal
^{95}Zr	3E+05	Aquatic Animal	9E+04	Riparian Animal

Table 6.2 Biota Concentration Guides (BCGs) for Water and Sediment (in Special Units) for Use in Aquatic System Evaluations. For use with measured radionuclide concentrations from co-located water and sediment.

Nuclide	BCG (water), pCi/L	Organism Responsible for Limiting Dose in Water	BCG (sediment), pCi/g	Organism Responsible for Limiting Dose in Sediment
^{241}Am	4E+02	Aquatic Animal	5E+03	Riparian Animal
^{144}Ce	2E+03	Aquatic Animal	3E+03	Riparian Animal
^{135}Cs	5E+02	Riparian Animal	4E+04	Riparian Animal
^{137}Cs	4E+01	Riparian Animal	3E+03	Riparian Animal
^{60}Co	4E+03	Aquatic Animal	1E+03	Riparian Animal
^{154}Eu	2E+04	Aquatic Animal	3E+03	Riparian Animal
^{155}Eu	3E+05	Aquatic Animal	3E+04	Riparian Animal
^{3}H	3E+08	Riparian Animal	4E+05	Riparian Animal
^{129}I	4E+04	Riparian Animal	3E+04	Riparian Animal
^{131}I	1E+04	Riparian Animal	5E+03	Riparian Animal
^{239}Pu	2E+02	Aquatic Animal	6E+03	Riparian Animal
^{226}Ra	4E+00	Riparian Animal	1E+02	Riparian Animal
^{228}Ra	3E+00	Riparian Animal	9E+01	Riparian Animal
^{125}Sb	4E+05	Aquatic Animal	7E+03	Riparian Animal
^{90}Sr	3E+02	Riparian Animal	6E+02	Riparian Animal
^{99}Tc	7E+05	Riparian Animal	4E+04	Riparian Animal
^{232}Th	3E+02	Aquatic Animal	1E+03	Riparian Animal
^{233}U	2E+02	Aquatic Animal	5E+03	Riparian Animal
^{234}U	2E+02	Aquatic Animal	5E+03	Riparian Animal
^{235}U	2E+02	Aquatic Animal	4E+03	Riparian Animal
^{238}U	2E+02	Aquatic Animal	2E+03	Riparian Animal
^{65}Zn	1E+01	Riparian Animal	1E+03	Riparian Animal
^{95}Zr	7E+03	Aquatic Animal	2E+03	Riparian Animal

Table 6.3 Biota Concentration Guides (BCGs) for Water and Soil (in SI Units) for Use in Terrestrial System Evaluations.

Nuclide	BCG (water), Bq/m^3	Organism Responsible for Limiting Dose in Water	BCG (soil), Bq/kg	Organism Responsible for Limiting Dose in Soil
^{241}Am	7E+06	Terrestrial Animal	1E+05	Terrestrial Animal
^{144}Ce	1E+08	Terrestrial Animal	5E+04	Terrestrial Animal
^{135}Cs	3E+08	Terrestrial Animal	1E+04	Terrestrial Animal
^{137}Cs	2E+07	Terrestrial Animal	8E+02	Terrestrial Animal
^{60}Co	4E+07	Terrestrial Animal	3E+04	Terrestrial Animal
^{154}Eu	8E+07	Terrestrial Animal	5E+04	Terrestrial Animal
^{155}Eu	1E+09	Terrestrial Animal	6E+05	Terrestrial Animal
^{3}H	9E+09	Terrestrial Animal	6E+06	Terrestrial Animal
^{129}I	2E+08	Terrestrial Animal	2E+05	Terrestrial Animal
^{131}I	7E+07	Terrestrial Animal	3E+04	Terrestrial Animal
^{239}Pu	7E+06	Terrestrial Animal	2E+05	Terrestrial Animal
^{226}Ra	3E+05	Terrestrial Animal	2E+03	Terrestrial Animal
^{228}Ra	3E+05	Terrestrial Animal	2E+03	Terrestrial Animal
^{125}Sb	3E+08	Terrestrial Animal	1E+05	Terrestrial Animal
^{90}Sr	2E+06	Terrestrial Animal	8E+02	Terrestrial Animal
^{99}Tc	6E+08	Terrestrial Animal	2E+05	Terrestrial Animal
^{232}Th	2E+06	Terrestrial Animal	6E+04	Terrestrial Animal
^{233}U	1E+07	Terrestrial Animal	2E+05	Terrestrial Animal
^{234}U	1E+07	Terrestrial Animal	2E+05	Terrestrial Animal
^{235}U	2E+07	Terrestrial Animal	1E+05	Terrestrial Animal
^{238}U	2E+07	Terrestrial Animal	6E+04	Terrestrial Animal
^{65}Zn	6E+06	Terrestrial Animal	2E+04	Terrestrial Animal
^{95}Zr	8E+07	Terrestrial Animal	4E+04	Terrestrial Animal

Table 6.4 Biota Concentration Guides (BCGs) for Water and Soil (in Special Units) for Use in Terrestrial System Evaluations.

Nuclide	BCG (water), pCi/L	Organism Responsible for Limiting Dose in Water	BCG (soil), pCi/g	Organism Responsible for Limiting Dose in Soil
^{241}Am	2E+05	Terrestrial Animal	4E+03	Terrestrial Animal
^{144}Ce	3E+06	Terrestrial Animal	1E+03	Terrestrial Animal
^{135}Cs	8E+06	Terrestrial Animal	3E+02	Terrestrial Animal
^{137}Cs	6E+05	Terrestrial Animal	2E+01	Terrestrial Animal
^{60}Co	1E+06	Terrestrial Animal	7E+02	Terrestrial Animal
^{154}Eu	2E+06	Terrestrial Animal	1E+03	Terrestrial Animal
^{155}Eu	3E+07	Terrestrial Animal	2E+04	Terrestrial Animal
^{3}H	2E+08	Terrestrial Animal	2E+05	Terrestrial Animal
^{129}I	6E+06	Terrestrial Animal	6E+03	Terrestrial Animal
^{131}I	2E+06	Terrestrial Animal	9E+02	Terrestrial Animal
^{239}Pu	2E+05	Terrestrial Animal	6E+03	Terrestrial Animal
^{226}Ra	8E+03	Terrestrial Animal	5E+01	Terrestrial Animal
^{228}Ra	7E+03	Terrestrial Animal	4E+01	Terrestrial Animal
^{125}Sb	7E+06	Terrestrial Animal	3E+03	Terrestrial Animal
^{90}Sr	5E+04	Terrestrial Animal	2E+01	Terrestrial Animal
^{99}Tc	2E+07	Terrestrial Animal	4E+03	Terrestrial Animal
^{232}Th	5E+04	Terrestrial Animal	2E+03	Terrestrial Animal
^{233}U	4E+05	Terrestrial Animal	5E+03	Terrestrial Animal
^{234}U	4E+05	Terrestrial Animal	5E+03	Terrestrial Animal
^{235}U	4E+05	Terrestrial Animal	3E+03	Terrestrial Animal
^{238}U	4E+05	Terrestrial Animal	2E+03	Terrestrial Animal
^{65}Zn	2E+05	Terrestrial Animal	4E+02	Terrestrial Animal
^{95}Zr	2E+06	Terrestrial Animal	1E+03	Terrestrial Animal

Table 6.5 Part 1 of Dose Factors and Common Parameters Spreadsheet. Most Probable K_d values for use in calculating generic BCGs for water and sediment in situations where co-located water and sediment samples are unavailable.

	Distribution Coefficients, K_d					
Nuclide	**Maximum Value L/kg (mL/g)**	**Reference $K_{d,max}$**	**Minimum Value L/kg (mL/g)**	**Reference $K_{d,min}$**	**Most Probable Value (a) L/kg (mL/g)**	**Reference $K_{d,mp}$**
^{241}Am	6.5E+05	T&M	8.5E+01	T&M	5.0E+03	T&M
^{144}Ce	1.0E+07	T&M	1.0E+02	RESRAD	1.0E+03	RESRAD
^{135}Cs	8.0E+04	T&M	1.7E+01	T&M	5.0E+02	RESRAD
^{137}Cs	8.0E+04	T&M	1.7E+01	T&M	5.0E+02	RESRAD
^{60}Co	3.0E+05	T&M	1.0E+02	RESRAD	1.0E+03	RESRAD
^{154}Eu	1.3E+05	T&M	2.0E+02	T&M	5.0E+02	T&M
^{155}Eu	1.3E+05	T&M	2.0E+02	T&M	5.0E+02	T&M
^{3}H	1.0E-04	KAH	1.0E-05	KAH	1.0E-03	KAH
^{129}I	1.0E+02	T&M	1.0E-05	KAH	1.0E+01	T&M
^{131}I	1.0E+02	T&M	1.0E-05	KAH	1.0E+01	T&M
^{239}Pu	1.0E+07	T&M	1.0E+02	T&M	2.0E+03	RESRAD
^{226}Ra	1.0E+03	T&M	1.0E-01	RESRAD	7.0E+01	RESRAD
^{228}Ra	1.0E+03	T&M	1.0E-01	RESRAD	7.0E+01	RESRAD
^{125}Sb	1.0E+03	KAH	1.0E-03	KAH	1.0E+00	KAH
^{90}Sr	4.0E+03	T&M	1.0E-01	RESRAD	3.0E+01	RESRAD
^{99}Tc	1.0E+02	T&M	1.0E-05	KAH	5.0E+00	T&M
^{232}Th	1.0E+06	T&M	1.2E+00	RESRAD	6.0E+04	RESRAD
^{233}U	5.0E+01	RESRAD	1.0E-01	RESRAD	5.0E+01	RESRAD
^{234}U	5.0E+01	RESRAD	1.0E-01	RESRAD	5.0E+01	RESRAD
^{235}U	5.0E+01	RESRAD	1.0E-01	RESRAD	5.0E+01	RESRAD
^{238}U	5.0E+01	RESRAD	1.0E-01	RESRAD	5.0E+01	RESRAD
^{65}Zn	1.0E+04	T&M	2.0E+00	RESRAD	2.0E+01	RESRAD
^{95}Zr	1.0E+05	T&M	1.0E+02	RESRAD	1.0E+03	RESRAD

T&M = Till and Meyer 1983; RESRAD = Yu et al. 1993; KAH = Estimation by K. A. Higley, Oregon State University.

(a) = "Most Probable" values shall be used to generate the generic BCGs for use in general screening in a case where only water or sediment data are available. This value may be modified using a site-representative K_d value in the analysis phase of the graded approach.

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7 Analysis Phase

The analysis phase of the graded approach contains three increasingly more detailed components of analysis for evaluating doses to biota: site-specific screening, site-specific analysis, and site-specific biota dose assessment. In the analysis phase, you are also increasingly moving away from the default parameters and assumptions used in the general screening phase of the graded approach. The amount of effort required for your biota dose evaluation and the information needed about site-specific conditions and receptors increase as you progress through the three components of the analysis phase. The amount of specialized assistance (e.g., in health physics, radioecology, and eco-risk assessment) that might be needed also increases as you progress through the components of the analysis phase. In return, the result will be a set of less conservative, more realistic and site-representative BCGs. **The rationale for selection of site-specific parameters applied in this phase shall be sufficiently documented when reporting your biota dose evaluation results**. Each of the three analysis components is described below.

7.1 Analysis Phase - Site-Specific Screening

Site-specific screening allows you to apply knowledge of site-specific conditions and receptors in your biota dose evaluation in place of the default parameter values and assumptions used in the general screening phase of the graded approach. For example, use of mean radionuclide concentrations in place of maximum values, taking into account time dependence and spatial extent of contamination, may be considered. Parameters representative of site-specific receptors also may be considered. These considerations and their application in site-specific screening are discussed below.

Questions to Consider in Determining Your Path Forward in Site-Specific Screening:

Can I use mean radionuclide concentrations rather than maximum values?

Does it make sense to adjust or re-define my evaluation area, using knowledge of the spatio-temporal extent of my contamination with respect to receptor habitats?

Are the "limiting organism types" corresponding to my media and radionuclides expected to be present in my evaluation area?

Do I have site-representative parameters (e.g., lumped parameters; B_{iv}s; K_ds) that can be used in place of default values?

7.1.1 Step 1: Assess the Representativeness of Your Input Data on Radionuclide Concentrations in Environmental Media and the Delineation of Your Evaluation Area

Spatial and temporal variability relative to the distribution of contamination in the evaluation area can be taken into account when evaluating doses to biota. Each of the elements presented below should be considered collectively as you proceed through this step.

7.1.1.1 Consider Using Mean Radionuclide Concentrations

Determine if mean radionuclide concentrations can be used in place of maximum concentrations. For example, use of mean values is appropriate and permitted in situations where time-series data are available and of sufficient quality. Spatial variability in the distribution of contamination can also be taken into account. Note that depending on the purpose of your application of the graded approach, you may be requested (e.g., by regulators or stakeholders) to use only maximum radionuclide concentration data rather than mean values. Detailed guidance on applying spatio-temporal considerations in determining mean radionuclide concentrations for use in the graded approach is provided in Module 2, Section 3.

7.1.1.2 Consider Refining the Evaluation Area

It may be useful to re-assess your rationale for delineating the evaluation area (e.g., breaking one large area into several smaller areas) through consideration of the quality and spatio-temporal distribution of radionuclide concentration data, the ecological susceptibility and habitats of the receptors, and the spatial distribution of contaminants with respect to these habitats. Refer to Module 2, Section 4 for detailed guidance in this area.

7.1.1.3 Consider Obtaining Additional Radionuclide Concentration Data

Consider collecting additional radionuclide concentration data. For an aquatic system evaluation, consider using co-located water and sediment data if you have not already done so.

7.1.2 Step 2: Re-Run the Screening Evaluation Using Revised Radionuclide Concentration Data and/or Evaluation Area

Here you are comparing your refined data on measured radionuclide concentrations corresponding to your original or re-defined evaluation area, with the generic BCGs. This is done by re-entering these revised data into the appropriate environmental data/BCG worksheet in the RAD-BCG Calculator. It is important to note that in this step you have not modified the initial, generic BCG values. They are the same generic BCGs that are used in the general screening phase of the graded approach. This step is considered a site-specific screen in that you are now making site-specific judgements relative to your measured radionuclide concentration data and your evaluation area. If the sum of fractions is less than 1.0, then you have passed the site-specific screening evaluation. Proceed to Section 8, Documenting Your Biota Dose Evaluation Results. If the sum of fractions is greater than 1.0, then continue to progress through the graded approach.

7.1.3 Step 3: Assess the Representativeness of Default Parameters and Assumptions Used in Deriving the Generic BCGs; Select Site-Specific Parameters and Generate Site-Specific BCGs

This step allows you to replace default parameters used in the general screening phase with site-representative parameters for use in site-specific screening. Each of the elements presented below should be considered collectively as you proceed through this step.

7.1.3.1 Identify Radionuclide-Specific Limiting Medium and Organism Type

Review the radionuclide-specific BCGs used in the general screening phase of the graded approach. First, identify the environmental medium and individual radionuclides from your evaluation that provide the greatest contribution to potential dose (e.g., medium concentration: BCG ratios that represent the largest contributors to the sum of fractions). Then, for each of these radionuclides, identify the limiting organism type from which the generic BCGs were derived. Limiting organism types corresponding to generic BCGs are listed for each radionuclide in Tables 6.1 - 6.4 and in the corresponding RAD-BCG Calculator spreadsheets. If you did not conduct a general screen prior to site-specific screening, go to the organism type table or spreadsheet that corresponds to the site-specific receptor you have chosen to use in your analysis. The site-specific receptor you select should be important to the structure and function of the community, in that protection of this organism within your evaluation area assures that all other organisms in your evaluation area are also protected. Some examples of receptors that could serve as good indicators of radiological impact are provided for your reference in Module 2, Section 2.1.3.

Selecting A Site-Specific Receptor

The receptor should be important to the structure and function of the community. It should: (1) be expected to receive a comparatively high degree of exposure (e.g., expected to receive a radiation dose to reproductive tissues which is relatively high per unit of radionuclide present in the ecosystem, in comparison to other receptors in the same community); (2) have a comparably high degree of radiosensitivity (e.g., radiation effects of concern occur at relatively low doses, in comparison with other receptors in the same community); and (3) exhibit a high degree of bioaccumulation.

7.1.3.2 Review and Select Site-Specific Lumped Parameters

The general screening phase uses a conservative default “lumped parameter” in the estimation of internal dose to an organism. The lumped parameter is based largely on empirical measurements of radionuclides in biological tissues of organisms collected in contaminated habitats. In cases where empirical measurements are unavailable or few in number, the lumped parameter is based on a conservative value derived using uncertainty analysis on the kinetic/allometric method (see Module 3, Section 3.5). The lumped parameter serves as a "natural integrator" of internal contamination in that it inherently reflects all pathways of intake by an organism. Here, in site-specific screening, lumped parameters representative of site-specific conditions and receptors are used to generate site-specific BCGs in place of the default lumped parameters that were used in generating the generic BCGs. This site-specific screening results in a less conservative, more realistic evaluation of potential doses to biota for your area of evaluation.

The initial values of the lumped parameters were specifically chosen to produce conservative (e.g., highly protective) BCGs. It is recognized that actual lumped parameters for a single radionuclide may range over several orders of magnitude, depending upon biotic and abiotic features of the environment. In step 3 you review the default lumped parameters used in deriving the BCGs for the appropriate organism type. The default lumped parameter values (and other input parameters) are contained in a set of organism type tables (Tables 7.1 - 7.4). The RAD-BCG Calculator contains similar tables which can be easily located (see Module 1, Section 4). Review and select lumped parameters representative of site-specific conditions and receptors you have selected for your evaluation area. These site-specific lumped parameters are entered into the appropriate organism type spreadsheet in the RAD-BCG Calculator and used to generate site-specific BCGs. Sources for lumped parameter values representative of your site-specific conditions and receptors include: (1) your own site-derived lumped parameters (e.g., B_{iv}s) for site-specific receptors; (2) values published in the scientific literature or in site-specific technical reports (e.g., from specialized ecological studies) for receptors that are comparable to site-specific receptors in your evaluation area; and (3) databases such as the pilot version of the Biota Dose Assessment Database of Environmental Parameters (BDAD), which is accessible via the Internet through the BDAC web site (http://homer.ornl.gov/oepa/public/bdac).

7.1.3.3 Review and Select Site-Representative K_ds

For aquatic system evaluations where co-located water and sediment samples are not available, recall that in the general screening phase a most probable K_d is used to calculate the environmental media radionuclide concentration and dose contribution of either the missing water or sediment component. Site-specific screening allows you to consider the use of a site-representative K_d value in place of the default most probable value that was used in the general screening phase. Minimum, maximum, and most probable K_d values for each radionuclide are provided in Table 6.5. Sources for K_d values representative of your site specific conditions include: (1) your own site-derived K_d values; (2) values published in the scientific literature or in site-specific technical reports; and (3) databases such as the pilot version of the BDAD, which is accessible via the Internet (see above). Site-representative K_d values are entered into the

Dose Factors and Common Parameters spreadsheet within the RAD-BCG Calculator and used in generating site-specific BCGs.

7.1.4 Step 4: Re-Run the Screening Evaluation and Compare Data on Radionuclide Concentrations in Environmental Media with Newly-Generated Site-Specific BCGs

The use of lumped parameters appropriate for site-specific conditions or receptors should result in more realistic, site-representative BCGs. When using the RAD-BCG Calculator, the generic BCGs listed in the aquatic and terrestrial system data entry/BCG worksheets are automatically updated with the newly generated BCGs, allowing for easy evaluation. If the sum of fractions (the summed ratios between the radionuclide concentrations in environmental media and the radionuclide-specific BCGs) is less than 1.0, the dose to the aquatic or terrestrial receptor is below the biota dose limit. Refer to Section 8, Reporting Your Biota Dose Evaluation Results. If the sum is greater than 1.0, further analysis is required. Proceed to Section 7.2, Site-Specific Analysis.

Entering Site-Specific Information into the RAD-BCG Calculator to Calculate Site-Specific BCGs

Lumped parameters may be modified in each of the organism type spreadsheets contained in the RAD-BCG Calculator. When working in the riparian or terrestrial animal spreadsheets, click on the "Lumped BCGs" button to allow these parameters to be modified. A "user supplied value" message will appear for each lumped parameter modified. Reset buttons for returning all values to their defaults are also featured.

Site-specific K_d values may be used by entering these values in place of the "most probable" values in the Dose Factors and Common Parameters spreadsheet.

The site-specific BCGs derived using these new parameters will show up in the organism-type spreadsheet, and also in the environmental data entry/BCG worksheets, allowing for easy comparison with site radionuclide concentration data previously entered.

7.2 Analysis Phase - Site-Specific Analysis

In site-specific analysis, a kinetic/allometric model is employed to conduct a more rigorous analysis of riparian animal and terrestrial animal organism types. Here you are conducting a very site-specific evaluation (essentially estimating an upper-bound dose) to a site-specific riparian or terrestrial animal of known characteristics (e.g., body mass, behavior, internal exposure pathways, and parameters). Recall that the general and site-specific screening approaches use a lumped parameter in the estimation of internal dose to an organism. The lumped parameter serves as a "natural integrator" of internal contamination in that it inherently reflects all pathways of intake by an organism. In site-specific analysis, simplistic, first-order kinetic modeling is used to examine the internal pathways of exposure for riparian animal and terrestrial animal receptors in greater detail. Appropriate parameters representing individual mechanisms (e.g., ingestion; inhalation) that contribute to internal dose are applied in place of the lumped parameter (one value which reflects all mechanisms contributing to internal dose). Appropriate values (e.g., organism body mass; ingestion rate; inhalation rate; biological uptake and elimination rates) representative of site-specific conditions and receptors are used in the estimation of internal dose and generation of site-specific BCGs. Allometric equations relating body size to many of these parameters (e.g., ingestion rate; inhalation rate; life span) are used in the estimation of internal dose. Alternatively, you can enter your own values in place of allometrically derived parameters. A correction factor for exposure area or organism residence time may also be applied for all organism types in site-specific analysis.

7.2.1 Step 5: Assess the Representativeness of Default Parameters and Assumptions Employed in Kinetic/Allometric Models; Select Site-Specific Parameters and Generate Site-Specific BCGs

This step allows you to examine and replace default parameters, assumptions, and allometric relationships used in kinetic/allometric models to derive BCGs for riparian animals and terrestrial animals. A correction factor for exposure area or organism residence time may also be applied for all organism types. Each of the elements presented below should be considered collectively when implementing this step.

7.2.1.1 Identify Radionuclide-Specific Limiting Medium and Organism Type

Review the radionuclide-specific BCGs used in the general or site-specific screening portions of the graded approach. First, identify the environmental medium and individual radionuclides from your evaluation that provide the greatest contribution to potential dose (e.g., medium concentration:BCG ratios that represent the largest contributors to the sum of fractions). Then, for each of these radionuclides, identify the limiting organism type from which the general or site-specific BCGs were derived. Limiting organism types corresponding to general BCGs are listed for each radionuclide in Tables 6.1 - 6.4, and in the corresponding RAD-BCG Calculator spreadsheets. If the riparian animal or terrestrial animal organism types are listed, then you may consider the guidance in Sections 7.2.1.2 - 7.2.1.4. If riparian or terrestrial animals are not listed as the limiting organism types, then you need only consider Section 7.2.1.2 below. If you did not conduct a general or site-specific screen prior to site-specific analysis, the proceeding statement applies to the site-specific receptor you have chosen to use in your analysis.

7.2.1.2 Consider Correction Factor for Exposure Area or Receptor Residence Time

A correction factor for exposure area or receptor residence time should be among the first parameters that you consider in site-specific analysis. Temporal and spatial variability can be taken into account when evaluating doses to biota. For example: (1) radionuclides will typically be distributed non-uniformly in the environment; and (2) organisms are typically distributed non-uniformly within the environment such that exposure may vary among individuals in an affected population (e.g., organisms may migrate into and out of areas of greater and lesser contamination). The general and site-specific screening portions of the graded approach assume for conservative purposes that an organism's residence time in the evaluation area is 100 percent and that the contaminated media are available 100 percent of the time to provide a source of exposure. These assumptions can be modified in site-specific analysis.

Using a Correction Factor for Exposure Area or Receptor Residence Time in the RAD-BCG Calculator

A correction factor for exposure area or receptor residence time, located in each of the organism-type spreadsheets, may be applied. Site-specific BCGs derived using these correction factors will appear in the organism-type spreadsheets, and also in the environmental data entry/BCG worksheet, allowing for easy comparison with site radionuclide concentration data previously entered.

Note that in cases where a riparian or terrestrial animal was indicated as the limiting organism in general or site-specific screening, it is possible that "scaling down" the correction factor to reflect a very small percentage of time an organism spends in the contaminated area may result in triggering the identification of a new limiting organism type (e.g., aquatic animal; terrestrial plant).

Correction Factor for Receptor Residence Time. The term "residence time" as used in the graded approach refers to the fraction of time that an organism resides in a radioactively contaminated area. In site-specific analysis, a correction factor for residence time (e.g., as a percentage of time) may be applied to take into account a specific receptor's home range, movements, and behavior relative to the evaluation area. This

Using the Kinetic/Allometric Method for Riparian and Terrestrial Animals: Entering Site-Representative Parameters into the Riparian Animal and Terrestrial Animal Spreadsheets contained in the RAD-BCG Calculator.

First, click on the "Allometric BCGs" button to allow these parameters to be modified.

Individual parameters (e.g., body mass; ingestion rate; inhalation rate; radionuclide uptake and retention factors) related to mechanisms providing an internal dose may be modified.

Changing the radionuclide-specific food source (B_{iv}) values in the aquatic animal and terrestrial plant spreadsheets will automatically change the BCG values in the riparian animal and terrestrial animal spreadsheets, respectively.

Site-specific BCGs derived using these new parameter values will show up in the riparian and terrestrial animal spreadsheets, and also in the environmental data entry/BCG worksheets, allowing for easy comparison to site radionuclide concentration data previously entered.

correction factor is entered into the appropriate organism type spreadsheet within the RAD-BCG Calculator and used in generating site-specific BCGs.

Correction Factor for Exposure Area. Radionuclides will typically be distributed non-uniformly in the environment. In site-specific analysis, a correction factor for contaminated area (e.g., as a percentage of time) can be applied to take into account an intermittent source of exposure to all receptors in the evaluation area. This correction factor is entered into the appropriate organism type spreadsheet within the RAD-BCG Calculator and used in generating site-specific BCGs.

7.2.1.3 Riparian and Terrestrial Animals: Review and Select Parameters Representative of Site-specific Conditions and Receptors

In site-specific analysis you can also modify the individual parameters that relate to internal exposure pathways for site-specific conditions and receptors. The RAD-BCG Calculator is designed for easy modification of these parameters and subsequent generation of site-specific BCGs that are derived using these new parameter values. Refer back to Table 4.1 for a complete list of parameters that can be modified when conducting a site-specific analysis.

7.2.1.4 Riparian and Terrestrial Animals: Review and Select Food Source Parameter Values Representative of Site-Specific Receptors

The kinetic/allometric method for deriving riparian and terrestrial animal BCGs uses a radionuclide-specific food source parameter in calculating the internal dose contribution for these organism types. The method uses radionuclide-specific default B_{iv}s for aquatic animals (listed in Table 7.1) and terrestrial plants (listed in Table 7.3) as the default food source parameter values for riparian and terrestrial animals respectively. You may review the appropriateness of these default food source parameter values (i.e., the B_{iv}s and their source organisms) and replace these with food source parameter values (B_{iv}s) corresponding to organisms which are more representative of the expected food sources for the riparian or terrestrial animal you have selected to use in your site-specific analysis. When using the RAD-BCG Calculator, changing the radionuclide-specific B_{iv} values in the aquatic animal and terrestrial plant spreadsheets will automatically change the BCG values in the riparian animal and terrestrial animal spreadsheets respectively. These new site-specific BCGs will also show up in the environmental system data entry/BCG worksheets, allowing for easy comparisons with previously entered radionuclide concentration data.

7.2.2 Step 6: Re-Run the RAD-BCG Calculator and Compare Data on Radionuclide Concentrations in Environmental Media with Newly-Generated Site-Specific BCGs

The use of parameter values and a correction factor appropriate for site-specific conditions or receptors should result in more realistic, site-representative BCGs. If the sum of fractions (the summed ratios between the radionuclide concentrations in environmental media and the radionuclide-specific BCGs) is less than 1.0, the dose to the aquatic or terrestrial receptor organism is below the biota dose limit. Refer to Section 8, Documenting Your Biota Dose Assessment Results. If the sum is greater than 1.0, further analysis is required.

7.3. Analysis Phase - Conducting a Site-Specific Biota Dose Assessment

7.3.1 Determine if Additional Analysis is Warranted

While the majority of the graded approach centers on the use of measured radionuclide concentrations in environmental media for comparison with BCGs, the site-specific biota dose assessment component of the analysis phase centers on the actual collection and analysis of biota from the evaluation area. This is so that measured concentrations of radionuclides in the tissues of biota can then be used to more realistically estimate the internal dose contribution to a site-specific receptor.

Should Additional Analysis or Remedial Action be Considered?

Factors to consider if initial general screening, site-specific screening, and site-specific analysis elements of the graded approach indicate a potential radiological impact to populations of biota within the evaluation area:

- The geographical extent of the contamination
- The magnitude of potential or observed effects of the contamination relative to the level of biological organization affected
- The likelihood that these effects could occur or will continue to occur
- The presence of genetically-isolated populations
- The ecological relationship of the affected area to the surrounding habitat
- The preservation of threatened or endangered species, or commercially or culturally valued species
- The recovery potential of the affected ecological resources and expected persistence of the radionuclides of concern under present site conditions
- The short- and long-term effects of the remedial alternatives on the habitat and the surrounding ecosystem
- Information obtained through a “lines of evidence” approach

Additional analysis may be warranted if biota dose evaluations using the screening and analysis methods described to this point continue to indicate that there is a potential adverse impact from radiation as a stressor to populations of biota (i.e., the BCGs are exceeded). An important point is that exceeding the BCGs should not force a mandatory decision regarding remediation of the evaluation area, but rather is an indication that further investigation is likely necessary. There are many factors that should be considered when deciding how to respond following a determination that the BCGs are exceeded (e.g., ecological relevance and susceptibility of the affected population; size of the contaminated area and persistence of contaminants; impacts of remediation alternatives).

If radionuclide concentrations in environmental media exceed the BCGs, two courses of action may be taken. On the one hand, it may be desirable to perform detailed dose assessments for relevant receptors. But given the potentially large expense that such a site-specific assessment could incur, removing the sources of ionizing radiation by reducing or eliminating discharges, or remediating existing environmental contamination, should also be considered. Site-specific conditions, especially the cost of eliminating discharges and/or remediating contaminated areas, will determine which approach is the more desirable.

The discussion below provides basic guidance on how to conduct a site-specific biota dose assessment.

7.3.2 An Important Note Concerning the Use of Available Biota Tissue Data

It is important to note that the use of measured concentrations of radionuclides in tissues of plants and animals in estimating internal dose is a reasonable and acceptable approach if adequate data are available. That is, if it can be justified that the available tissue data (1) are representative of species within the evaluation area that are capable of receiving the highest dose, and (2) reflect a representative sampling of the population within the evaluation area. These considerations are especially important in cases where biota tissue data becomes available as a result of opportunistic sampling (e.g., road kills; hunting). Detailed guidance regarding the selection of representative receptor species, and representative population and exposure considerations, is provided in Module 2, Section 6. If available biota tissue data is determined to be inadequate, then collection and analysis of biota from the evaluation area will be required. The internal dose conversion factors for biota, and external dose conversion factors for water, sediment and soil used to derive the generic BCGs in the graded approach are provided in Table 7.9. These values, together with your measured radionuclide concentrations in water, sediment and soil, and biota tissue data, can be used to estimate an upper-bound dose to a receptor.

7.3.3 Step 1: Assemble a Biota Dose Assessment Team

The composition of the biota dose assessment team is critical to designing and conducting a technically sound dose assessment. Together, team members must have a complete set of the relevant skills necessary to do the work. Necessary skills will vary somewhat by site, but should include ecology, health physics, radioecology, and specialists in fate and transport of contaminants for the environmental media of interest. Depending on the regulatory compliance agreements and monitoring program requirements that exist at the site, it may also be desirable to have a regulatory specialist participate in the assessment. Other site-specific conditions will dictate the need for other related skills within the team or the need for direct stakeholder participation at this level.

7.3.4 Step 2: Review Requirements

To perform a detailed dose assessment, it will usually be necessary to design and conduct a relatively comprehensive environmental study of the sources of ionizing radiation and the potential receptors (e.g., to involve collection and analysis of site-specific organisms within the evaluation area). Such a study should be consistent with the requirements of applicable DOE Orders and guidance, Federal regulations, and State regulations. Particularly important are the following DOE Orders:

- Order 5400.1, *General Environmental Protection Program*
- Order 5400.5, *Radiation Protection of the Public and the Environment*
- Order 414.1A, *Quality Assurance*

These Orders, and the Federal legislation and Executive Orders cited therein, applicable State regulations, and applicable DOE site-specific requirements should be consulted during the design and conduct of field and laboratory studies to support dose assessments.

7.3.5 Step 3: Review Assumptions

Two assumptions will most likely be implicit in the dose assessment:

- Because it will be impossible to assess dose to all potential receptor populations in the area of contamination, one (to several) receptor species must serve as surrogates for all potentially exposed populations. Therefore, species selected for dose assessment should be among those that are most sensitive to the effects of ionizing radiation, helping to ensure that all populations are protected.

- The population of the receptor species for which doses are assessed is defined as those individuals living within the contaminated area. This assumption is consistent with the EPA definition of “population.” This assumption is conservative to the extent that individuals move in and out of the contaminated area.

Any deviations from the above assumptions when designing or conducting the dose assessment should be documented.

7.3.6 Recommended Approaches to Designing and Conducting the Dose Assessment

It is strongly recommended that all dose assessments be designed and conducted following the *Guidelines for Ecological Risk Assessment* (EPA 1998). Use of these guidelines will help ensure that the resulting dose assessments are technically sound. In addition, some of the steps in the ecological risk process (e.g., development of a site conceptual model) will be useful for assessing toxicological risks associated with some radionuclides (e.g., uranium isotopes) as well as the ecological risks from other co-occurring substances or stressors within the contaminated area (e.g., hazardous chemicals). The site conceptual model will also be useful for understanding the large-scale distribution of contaminants and the sources of ecological risk to the populations within and beyond the study area. *Guidelines for Ecological Risk Assessment* can be downloaded from the DOE EH-41 Dose and Risk Assessment web site (http://www.eh.doe.gov/oepa/risk). An electronic tool for developing a site conceptual model is also available at this web site. If multiple stressors are present and need to be evaluated, then appropriate guidance concerning cumulative risk assessment should be considered (e.g., see EPA 1997b).

In addition to the references found in EPA's *Guidelines for Ecological Risk Assessment*, the following references and materials should be useful, many of which are also available on the EH-41 Dose and Risk Assessment web site: (http:/www.eh.doe.gov/oepa/risk).

- G.R. Bilyard, H. Beckert, J.J. Bascietto, C.W. Abrams, S.A. Dyer, and L.A. Haselow. 1997. *Using the Data Quality Objectives Process During the Design and Conduct of Ecological Risk Assessments.* DOE/EH-0544, prepared for U.S. Department of Energy, Office of Environmental Policy and Assistance by Pacific Northwest National Laboratory, Richland, Washington.

- B.E. Sample, M.S. Aplin, R.A. Efroymson, G.W. Suter II, and C.J.E. Welsh. 1997. *Methods and Tools for Estimation of the Exposure of Terrestrial Wildlife to Contaminants.* ORNL/TM-13391, prepared for U.S. Department of Energy, Office of Environmental Policy and Assistance by Oak Ridge National Laboratory, Oak Ridge, Tennessee.

- U.S. Department of Energy. 1991. *Environmental Regulatory Guide for Radiological Effluent Monitoring and Environmental Surveillance.* DOE/EH-0173T, Assistant Secretary for Environment, Safety and Health, U.S. Department of Energy, Washington, D.C.

- U.S. Department of Energy. 1998. *Compendium of EPA-Approved Analytical Methods for Measuring Radionuclides in Drinking Water.* Office of Environmental Policy and Assistance, Assistant Secretary for Environment, Safety and Health, U.S. Department of Energy, Washington, D.C.

- U.S. Environmental Protection Agency (EPA). 1997. *Ecological Risk Assessment Guidance for Superfund: Process for Designing and Conducting Ecological Risk Assessments.* EPA 540-R-97-006 (Interim Final June 5, 1997), U.S. EPA, Washington, D.C.

7.3.7 Designing and Conducting the Dose Assessment

The *Guidelines for Ecological Risk Assessment* (EPA 1998) provide a flexible framework for assessing ecological risks. The framework consists of three major phases of activity: problem formulation, analysis, and risk characterization. Activities within each of these phases can be summarized as follows:

In *problem formulation,* risk assessors evaluate goals and select assessment endpoints, prepare the conceptual model, and develop an analysis plan. During the *analysis phase*, assessors evaluate exposure to stressors and the relationship between stressor levels and ecological effects. In the third phase, *risk characterization*, assessors estimate risk (or dose) through integration of exposure and stressor-response profiles, describe risk by discussing lines of evidence and determining ecological adversity, and prepare a report. A more detailed “primer” on how to evaluate doses to biota through the ecological risk assessment process is provided in Module 2, Section 1.

> **Assessment Endpoint**
>
> *An explicit expression of the environmental value that is to be protected, operationally defined by an ecological entity and its attributes. For example, salmon are valued ecological entities; reproduction and age class structure are some of their important attributes. Together “salmon reproduction and age class structure” form an assessment endpoint.*

The dose assessment team has considerable latitude over how activities should be conducted within each phase of the assessment. The dose limits recommended in Module 1, Section 1.1 do not compromise this flexibility, but provide a major advantage for the dose assessment team because they define doses below which risks to populations are assumed not to occur. This definition simplifies those steps in the ecological risk assessment process that involve assessing the relationship between stressor levels and ecological effects, characterizing, estimating, and assessing risks. Caution should be exercised if more restrictive limits are selected, to ensure that the supporting effects data are of high quality, reproducible, and clearly relevant to protection of natural populations. In cases where evaluating dose to individual organisms is needed, you should consider the guidance provided in Module 2, Section 8. The following brief overview of the ecological risk assessment process emphasizes how the recommended dose limits simplify the risk assessment process for the dose assessment team.

Problem Formulation. In this first phase, the purpose of the dose assessment is clearly defined, the problem is clearly stated, and a plan for analyzing and characterizing risks is developed. As seen in Figure 7.1, available information is integrated to develop a site conceptual model and define assessment endpoints. The analysis plan is derived from the assessment endpoints and conceptual model. As the risk assessment proceeds, assessment endpoints and/or the site conceptual model may be refined, requiring subsequent revisions to the analysis plan.
In the problem formulation phase, the dose assessment team will perform the above steps in much the same way as would an ecological risk-assessment team. For this reason, the dose assessment team should coordinate its activities with other ecological risk assessment efforts

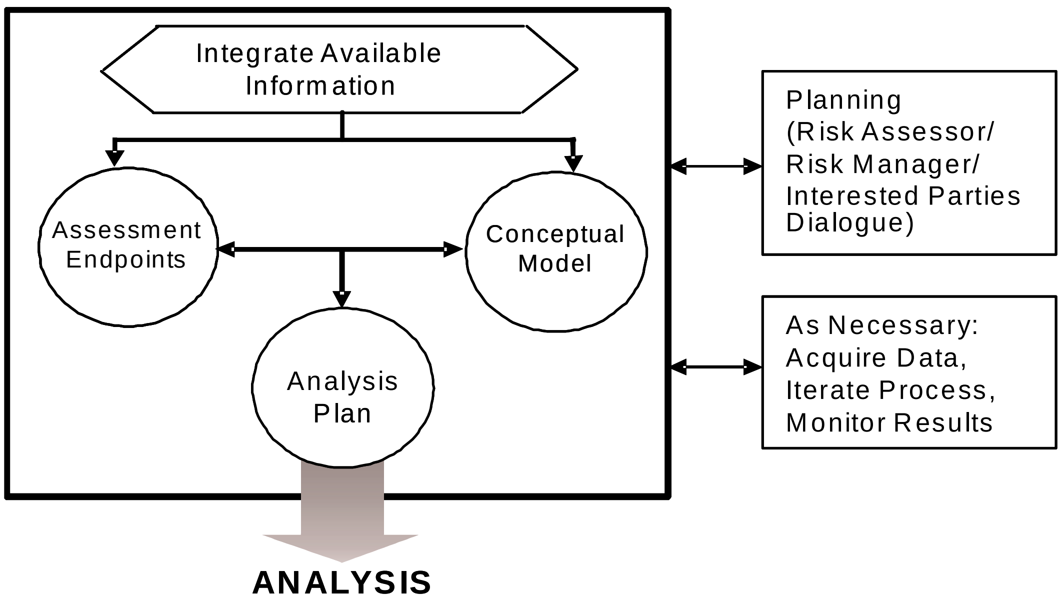

Figure 7.1 Problem Formulation, Phase 1 of Dose Assessment (from EPA 1998)

so that the identification of assessment endpoints and the development of site conceptual models are coordinated. The dose assessment team will, however, need to consider two factors that an ecological risk-assessment team might not. First, the analysis plan should select receptor species resident at the specific site that are known to be radiosensitive. Second, certain considerations are important to collecting biological samples for dosimetric assessments. Collection of biological samples is done to provide more realistic estimates of internal dose to organisms. Considerations for collecting biological samples are reviewed in detail in Module 2, Section 6. Additional considerations for both dose assessments and ecological risk assessments are the movement of receptors into and out of the contaminated area and the distribution of receptors relative to the contaminated area. These considerations are particularly relevant to motile species, small "hot spots" of contamination, and areas where the concentrations of contaminants vary spatially. In such cases, it may be expedient to better

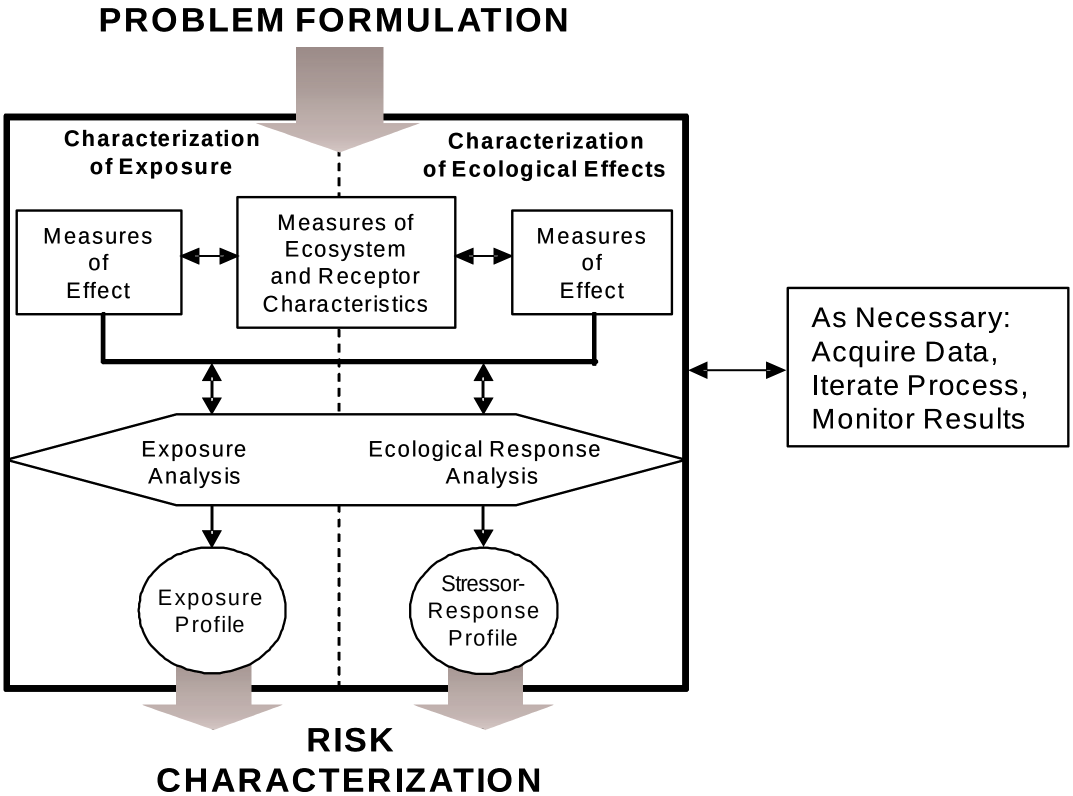

Figure 7.2 Analysis, Phase 2 of Dose Assessment (from EPA 1998)

define the distribution of organisms in time and/or space relative to the contaminated area. For example, individuals of a species may reside year-round within the region but move into and out of the contaminated area, necessitating the collection of data on duration of exposure. Or, ecologically significant species of plants may be located in only one part of the contaminated area and may be exposed to radionuclide concentrations that are above or below mean values for the area. Refer to Module 2, Sections 2 through 5 for detailed guidance in these areas.

Analysis Phase. The exposure profile and stressor-response profile (i.e., ecological effects profile) are estimated during this phase (see Figure 7.2). The dose assessment team should focus on the exposure side of the analysis phase because deleterious effects on receptor populations are assumed not to occur below the recommended limits of 0.1 rad/d or 1.0 rad/d, as appropriate.

In this phase, the dose assessment team should focus on identifying exposure pathways and quantifying exposure. The site conceptual model is the basis for identifying exposure pathways. Quantifying exposure is achieved by assessing the strengths and limitations of the existing site-specific environmental data on radionuclide contamination, collecting additional supplemental data as needed, and quantitatively analyzing exposure. If supplemental data are needed, the analysis plan may also need to be revised.

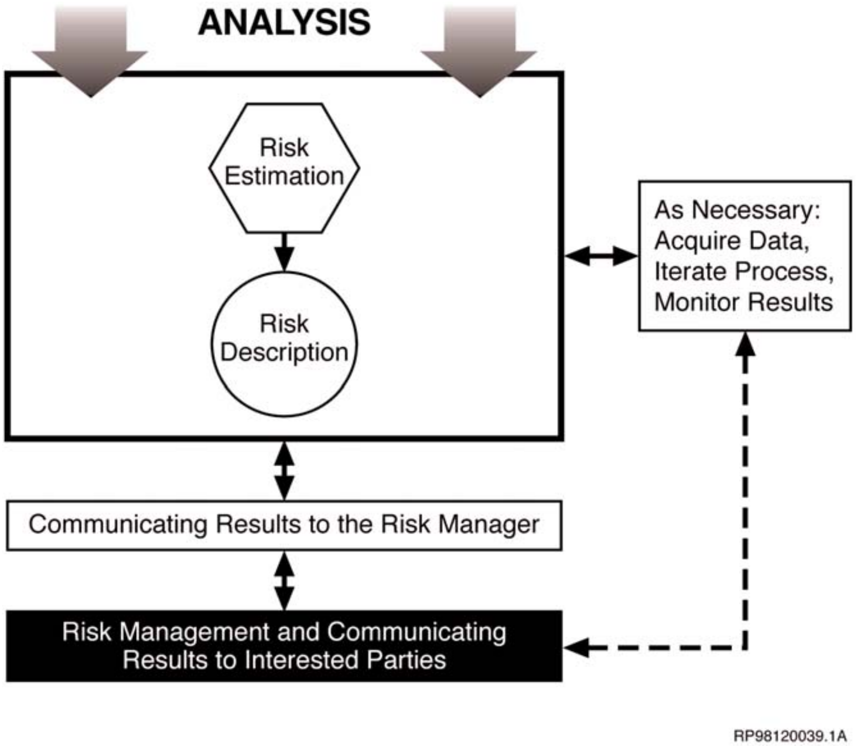

Figure 7.3 Risk Characterization, Phase 3 of Dose Assessment (from EPA 1998)

Risk Characterization. In this phase, doses are estimated and described (see Figure 7.3). The recommended limits again simplify this process since adverse effects on receptor populations are assumed not to occur at exposures below the recommended limits. Plants and animals may also be simultaneously exposed to other stressors, such as noise and hazardous chemicals. At present, no consensus exists within the scientific community about what the cumulative impacts are of simultaneous exposure to ionizing radiation and other anthropogenic stressors, or how to measure them. This factor should be considered when estimating and describing the risks associated with doses of ionizing radiation, if only qualitatively. In cases where exposure of biota to ionizing radiation exceeds the biota dose limits, a consideration of cumulative impacts from radiation and other stressors present may be warranted. Refer to *EPA's Guidance on Cumulative Risk Assessment*, Part 1, Planning and Scoping (EPA 1997b) for an introduction to this topic.

Table 7.1 Aquatic Animal Biota Concentration Guide Spreadsheet. BCGs are for use with radionuclide concentrations from co-located water and sediment. The default lumped parameter values (B_{iv}s) listed here were used to derive the generic BCGs for the general screening phase. These lumped parameter values may be replaced with site-representative values in the site-specific screening component of the analysis phase.

	Derived Concentrations		Bioaccumulation Factor	
Nuclide	**BCG (sediment) Bq/kg**	**BCG (water) Bq/m^3**	**B_{iv}, Organism to Water (L/kg) Fresh Mass**	**Water B_{iv} Reference[(a)]**
^{241}Am	3E+07	2E+04	400	CRITR
^{144}Ce	1E+06	6E+04	9000	T&M, Table 5.41
^{135}Cs	3E+07	5E+05	22000	T&M, Table 5.41
^{137}Cs	2E+06	4E+04	22000	T&M, Table 5.41
^{60}Co	6E+05	1E+05	2000	T&M, Table 5.41
^{154}Eu	1E+06	8E+05	600	GENII
^{155}Eu	1E+07	1E+07	600	GENII
^{3}H	3E+08	2E+11	0.2	CRITR
^{129}I	2E+07	4E+07	220	T&M, Table 5.41
^{131}I	3E+06	6E+06	220	T&M, Table 5.41
^{239}Pu	3E+08	7E+03	1000	T&M, Table 5.41
^{226}Ra	5E+05	4E+02	3200	T&M, Table 5.41
^{228}Ra	1E+06	3E+02	3200	Based on ^{226}Ra
^{125}Sb	3E+06	1E+07	100	T&M, Table 5.41
^{90}Sr	1E+06	2E+06	320	T&M, Table 5.41
^{99}Tc	2E+07	9E+07	78	T&M, Table 5.41
^{232}Th	1E+08	1E+04	80	T&M, Table 5.41
^{233}U	4E+08	7E+03	1000	T&M, Table 5.41
^{234}U	1E+08	7E+03	1000	T&M, Table 5.41
^{235}U	4E+06	8E+03	1000	T&M, Table 5.41
^{238}U	2E+06	8E+03	1000	T&M, Table 5.41
^{65}Zn	2E+06	7E+04	17000	T&M, Table 5.41
^{95}Zr	9E+05	3E+05	1600	T&M, Table 5.41

(a) T&M = Till and Meyer 1983; GENII = Napier et al. 1988; CRITR = Baker and Soldat 1992

Table 7.2 Part 1 of the Riparian Animal Biota Concentration Guide Spreadsheet. BCGs are for use with radionuclide concentrations from co-located water and sediment. The default lumped parameter values were used to derive the generic BCGs for the general screening phase. These lumped parameter values may be replaced with site-representative values in the site-specific screening component of the analysis phase.

Nuclide	BCG (sediment) Bq/kg	BCG (water) Bq/m^3	Lumped Parameter, Bq/kg (animal - wet weight)	
			per Bq/kg sediment	per Bq/L water
^{241}Am	2E+05	5E+04	3.E-03	1.E+01
^{144}Ce	1E+05	2E+06	5.E-04	3.E+01
^{135}Cs	2E+06	2E+04	3.E-01	5.E+04
^{137}Cs	1E+05	2E+03	3.E-01	5.E+04
^{60}Co	5E+04	2E+05	1.E-02	2.E+02
^{154}Eu	1E+05	2E+06	4.E-03	2.E+01
^{155}Eu	1E+06	3E+07	3.E-03	2.E+01
^{3}H	1E+07	1E+10	4.E-01	8.E-01
^{129}I	1E+06	1E+06	3.E-01	6.E+02
^{131}I	2E+05	5E+05	1.E-01	2.E+02
^{239}Pu	2E+05	2E+04	3.E-03	3.E+01
^{226}Ra	4E+03	2E+02	3.E-02	8.E+02
^{228}Ra	3E+03	1E+02	3.E-02	8.E+02
^{125}Sb	3E+05	2E+08	4.E-04	3.E-01
^{90}Sr	2E+04	1E+04	2.E+00	6.E+03
^{99}Tc	2E+06	2E+07	5.E-02	3.E+01
^{232}Th	5E+04	6E+04	2.E-03	1.E+00
^{233}U	2E+05	3E+04	4.E-03	3.E+01
^{234}U	2E+05	3E+04	4.E-03	3.E+01
^{235}U	1E+05	3E+04	4.E-03	3.E+01
^{238}U	9E+04	3E+04	4.E-03	3.E+01
^{65}Zn	5E+04	5E+02	2.E+00	2.E+05
^{95}Zr	9E+04	1E+06	3.E-03	4.E+01

(a) CRITR = Baker and Soldat 1992; T&M = Till and Meyer 1983; GENII = Napier et al. 1988; W&S = Whicker and Schultz 1982; KAH = K. A. Higley, Oregon State University.

Table 7.3 Terrestrial Plant Biota Concentration Guide Spreadsheet. The default lumped parameter values (B_{iv}s) listed here were used to derive the generic BCGs for the general screening phase. These lumped parameter values may be replaced with site-representative values in the site-specific screening component of the analysis phase.

Nuclide	BCG (soil) Bq/kg	BCG (water) Bq/m^3	Bioaccumulation Factor, B_{iv}	
			Bq/kg (plant - wet weight) per Bq/kg (soil)	Reference[(a)]
^{241}Am	8E+05	3E+10	8E-03	T&M, Table 5.16, Table 5.18
^{144}Ce	5E+05	1E+09	4E-02	T&M, Table 5.16, Table 5.17
^{135}Cs	1E+06	3E+10	1E+01	T&M, Table 5.16, Table 5.17
^{137}Cs	8E+04	2E+09	1E+01	T&M, Table 5.16, Table 5.17
^{60}Co	2E+05	6E+08	2E-01	T&M, Table 5.16, Table 5.17
^{154}Eu	5E+05	1E+09	4E-02	Estimated from Ce value by KAH
^{155}Eu	6E+06	1E+10	4E-02	Estimated from Ce value by KAH
^{3}H	6E+07	3E+11	1E+00	Estimated from NUREG 1.109
^{129}I	6E+06	2E+10	4E-01	T&M, Table 5.16, Table 5.17
^{131}I	9E+05	3E+09	4E-01	T&M, Table 5.16, Table 5.17 for ^{129}I
^{239}Pu	5E+05	3E+11	1E-02	T&M, Table 5.16, Table 5.18
^{226}Ra	1E+04	5E+08	1E-01	T&M, Table 5.16, Table 5.18
^{228}Ra	9E+03	1E+09	1E-01	T&M, Table 5.16, Table 5.18 from ^{226}Ra
^{125}Sb	1E+06	3E+09	1E-02	From GENII, Food Transfer Library
^{90}Sr	1E+05	1E+09	4E+00	T&M, Table 5.16, Table 5.17
^{99}Tc	8E+05	2E+10	8E+00	From GENII, Food Transfer Library
^{232}Th	9E+05	1E+11	1E-03	T&M, Table 5.16, Table 5.18
^{233}U	2E+06	4E+11	4E-03	T&M, Table 5.16, Table 5.18 from ^{238}U
^{234}U	2E+06	1E+11	4E-03	T&M, Table 5.16, Table 5.18 from ^{238}U
^{235}U	1E+06	4E+09	4E-03	T&M, Table 5.16, Table 5.18 from ^{238}U
^{238}U	6E+05	2E+09	4E-03	T&M, Table 5.16, Table 5.18
^{65}Zn	9E+05	2E+09	3E-01	T&M, Table 5.16, Table 5.17
^{95}Zr	4E+05	9E+08	3E-02	T&M, Table 5.16, Table 5.17

(a) T&M = Till and Meyer 1983; GENII = Napier et al. 1988; KAH = K. A. Higley, Oregon State University.

Table 7.4 Part 1 of the Terrestrial Animal Biota Concentration Guide Spreadsheet. The default lumped parameter values listed here were used to derive the generic BCGs for the general screening phase. These lumped parameter values may be replaced with site-representative values in the site-specific screening component of the analysis phase.

Nuclide	BCG (soil) Bq/kg	BCG (water) Bq/m^3	Lumped Parameters	
			Terrestrial Animal to Soil Bq/kg (animal - wet wt.) / Bq/kg (soil)	Terrestrial Animal to Water Bq/kg (animal - wet wt.)/Bq/L (water)
^{241}Am	1E+05	7E+06	4E-03	9E-02
^{144}Ce	5E+04	1E+08	6E-03	8E-03
^{135}Cs	1E+04	3E+08	1E+02	3E+00
^{137}Cs	8E+02	2E+07	1E+02	3E+00
^{60}Co	3E+04	4E+07	8E-02	1E-01
^{154}Eu	5E+04	8E+07	5E-03	1E-01
^{155}Eu	6E+05	1E+09	4E-03	9E-02
^{3}H	6E+06	9E+09	1E+00	1E+00
^{129}I	2E+05	2E+08	3E+00	3E+00
^{131}I	3E+04	7E+07	3E+00	1E+00
^{239}Pu	2E+05	7E+06	3E-03	9E-02
^{226}Ra	2E+03	3E+05	6E-02	4E-01
^{228}Ra	2E+03	3E+05	6E-02	4E-01
^{125}Sb	1E+05	3E+08	4E-04	5E-03
^{90}Sr	8E+02	2E+06	8E+01	3E+01
^{99}Tc	2E+05	6E+08	3E+00	8E-01
^{232}Th	6E+04	2E+06	2E-03	5E-02
^{233}U	2E+05	1E+07	4E-03	5E-02
^{234}U	2E+05	1E+07	4E-03	5E-02
^{235}U	1E+05	2E+07	4E-03	5E-02
^{238}U	6E+04	2E+07	4E-03	5E-02
^{65}Zn	2E+04	6E+06	7E+00	2E+01
^{95}Zr	4E+04	8E+07	4E-03	3E-02

Table 7.5 Part 2 of the Riparian Animal Biota Concentration Guide Spreadsheet. The default parameter values listed here relating to the uptake, retention and biological decay rates of radionuclides for a riparian animal receptor may be replaced with site-representative values in the site-specific analysis component of the analysis phase.

Nuclide	Fraction of Intake Retained f_1 (unitless)	Biological Decay Constant λ_{bio} (d^{-1})	$\lambda bio = ln(2)/(aW^b)$		λ_{bio} (d^{-1}) Reference[(a)]
			a (constant)	b (constant)	
^{241}Am	1E-03	5.53E-04	0.8	0.81	ICRP 30, Part 4
^{144}Ce	3E-04	3.46E-04	1.4	0.8	ICRP 30, Part 1
^{135}Cs	1E+00	2.24E-02	3.5	0.24	W&S
^{137}Cs	1E+00	2.24E-02	3.5	0.24	W&S
^{60}Co	5E-02	3.01E-02	2.6	0.24	W&S
^{154}Eu	1E-03	3.46E-04	1.4	0.8	ICRP 30, Part 3
^{155}Eu	1E-03	3.46E-04	1.4	0.8	ICRP 30, Part 3
^{3}H	1E+00	5.72E-03	0.82	0.55	W&S
^{129}I	1E+00	3.13E-02	6.8	0.13	W&S
^{131}I	1E+00	3.13E-02	6.8	0.13	W&S
^{239}Pu	1E-03	5.53E-04	0.8	0.81	ICRP 30, Part 4
^{226}Ra	2E-01	3.58E-02	2	0.25	Estimated by KAH
^{228}Ra	2E-01	3.58E-02	2	0.25	Estimated by KAH
^{125}Sb	1E-02	1.43E-01	0.5	0.25	ICRP 30, Part 3
^{90}Sr	3E-01	6.11E-04	107	0.26	W&S
^{99}Tc	8E-01	6.11E-02	0.3	0.4	ICRP 30, Part 2
^{232}Th	2E-04	1.34E-04	3.3	0.81	ICRP 30, Part 1
^{233}U	5E-02	6.81E-02	0.8	0.28	ICRP 30, Part 1
^{234}U	5E-02	6.81E-02	0.8	0.28	ICRP 30, Part 1
^{235}U	5E-02	6.81E-02	0.8	0.28	ICRP 30, Part 1
^{238}U	5E-02	6.81E-02	0.8	0.28	ICRP 30, Part 1
^{65}Zn	5E-01	7.16E-04	100	0.25	ICRP 30, Part 2
^{95}Zr	2E-03	7.16E-04	100	0.25	ICRP 30, Part 1

(a) CRITR = Baker and Soldat 1992; T&M = Till and Meyer 1983; GENII = Napier et al. 1988; W&S = Whicker and Schultz 1982; KAH = K. A. Higley, Oregon State University.

Table 7.6 Part 3 of the Riparian Animal Biota Concentration Guide Spreadsheet. Riparian animal default kinetic/allometric relationship parameter values listed here may be replaced with site-representative values in the site-specific analysis component of the analysis phase.

Parameter	Equation	Descriptions	Value(s)	Reference
W		Body mass (g)	8800	default for raccoon or river otter
r	$r = \frac{a}{dc} 70 M^{0.75}$	Food intake rate (g/d)	325.1377223	W&S, Vol. II, p. 43, equation 78
		a: ratio of active to basal metabolic rate	2	
		70: constant	70	
		d: fraction of energy ingested that is assimilated or oxidized	0.44	
		c: caloric value of food, kcal/g	5	
		M: body mass in kg (=W*0.001)	8.8	
		0.75: exponent in calculation	0.75	
$r_{sediment}$	$r_{sediment} = 0.1\, r$	Sediment Intake Rate (g/d)	32.5137723	EPA Wildlife Exposure Factor Handbook, Vol. 1, p. 4-22
		r: food intake rate, g/d	325.1377223	
		0.1: fraction of sediment in diet, expressed as % of food diet, dry wt.	0.1	
T_{ls}	$T_{ls,\max,} = 1.02 M^{0.30}$	Maximum Lifespan	1.958596497	Calder, p. 316, Table 11-5
		1.02: constant in equation	1.02	
		M = body mass in kg	8.8	
		0.30: exponent in calculation	0.30	
r_b	$r_b = 0.481 M^{0.76}$	Inhalation rate (m^3/d)	2.511608286	Pedley, p. 15, Table V., adjusted to provide units of m^3/d
		0.481: constant in calculation to give m^3/d	0.481	
		M = body mass in kg	8.8	
		0.76: exponent in equation	0.76	
$r_{inhalation}$	$r_{inhalation} = x\ r_b$	Sediment inhalation rate (g/d)	0.000251161	derived
		x: airborne dust loading, g/m^3	0.0001	
		r_b: inhalation rate (see above)	2.511608286	
I_w	$I_w = 0.099 M^{0.90}$	Water consumption rate (L/d)	0.700921852	EPA Wildlife Exposure Factor Handbook, Vol. 1, p. 3-10, equation 3-17
		0.099: constant in equation	0.099	
		see above equation, M: body mass in kg (=W*0.001)	8.8	
		0.9: exponent in calculation	0.9	

Table 7.7 Part 2 of the Terrestrial Animal Biota Concentration Guide Spreadsheet. The default parameter values listed here relating to the uptake, retention, and biological decay rates of radionuclides for a terrestrial animal receptor may be replaced with site-representative values in the site-specific analysis component of the analysis phase.

Nuclide	Fraction of Intake Retained f_1 (unitless)	Biological Decay Constant λ_{bio}, d^{-1}	$\lambda_{bio} = \ln(2) / (aW^b)$		λ_{bio} (d^{-1}) Reference [a]	PT/IT [b]
			a (constant)	b (exponent)		
^{241}Am	1E-03	7.09E-02	0.8	0.81	ICRP 30 Part 4	250
^{144}Ce	3E-04	4.18E-02	1.4	0.8	ICRP 30 Part 1	16
^{135}Cs	1E+00	9.43E-02	3.5	0.24	Whicker & Schultz	0.8
^{137}Cs	1E+00	9.43E-02	3.5	0.24	Whicker & Schultz	0.8
^{60}Co	5E-02	1.27E-01	2.6	0.24	Whicker & Schultz	7
^{154}Eu	1E-03	4.18E-02	1.4	0.8	ICRP 30 Part3	30
^{155}Eu	1E-03	4.18E-02	1.4	0.8	ICRP 30 Part 3	30
^{3}H	1E+00	1.54E-01	0.82	0.55	Whicker & Schultz	1
^{129}I	1E+00	6.82E-02	6.8	0.13	Whicker & Schultz	0.7
^{131}I	1E+00	6.82E-02	6.8	0.13	Whicker & Schultz	0.7
^{239}Pu	1E-03	7.09E-02	0.8	0.81	ICRP 30 Part 3	4000
^{226}Ra	2E-01	1.6E-01	2	0.25	Estimated by KAH	3
^{228}Ra	2E-01	1.6E-01	2	0.25	Estimated by KAH	3
^{125}Sb	1E-02	6.40E-01	0.5	0.25	ICRP 30 Part 3	3.5
^{90}Sr	3E-01	2.90E-03	107	0.26	Whicker & Schultz	200
^{99}Tc	8E-01	6.71E-01	0.3	0.4	ICRP 30 Part 2	5
^{232}Th	2E-04	1.72E-02	3.3	0.81	ICRP 30 Part 1	750
^{233}U	5E-02	3.65E-01	0.8	0.28	ICRP 30 Part 1	7000
^{234}U	5E-02	3.65E-01	0.8	0.28	ICRP 30 Part 1	7000
^{235}U	5E-02	3.65E-01	0.8	0.28	ICRP 30 Part 1	3500
^{238}U	5E-02	3.65E-01	0.8	0.28	ICRP 30 Part 1	4000
^{65}Zn	5E-01	3.20E-03	100	0.25	ICRP 30 Part 2	1
^{95}Zr	2E-03	3.20E-03	100	0.25	ICRP 30 Part 1	10

(a) KAH = K.A. Higley, Oregon State University; Whicker and Schultz, 1982; (b) PT/IT = Factor used in assessing the relative contribution to internal dose from animal inhalation versus ingestion.

Table 7.8 Part 3 of Terrestrial Animal Biota Concentration Guide Spreadsheet. Terrestrial animal default kinetic/allometric relationship parameter values listed here may be replaced with site-representative values in the site-specific analysis component of the analysis phase.

Parameter	Equation	Descriptions	Value(s)	Reference
W		Body mass (g)	22	default for deer mouse
r	$r = \frac{a}{dc}\ 70\ M^{\ 0.75}$	Food intake rate (g/d)	3.635150245	W&S, Vol. II, p. 43, equation 78
		a: ratio of active to basal metabolic rate	2	
		70: constant	70	
		d: fraction of energy ingested that is assimilated or oxidized	0.44	
		c: caloric value of food, kcal/g	5	
		M: body mass in kg (=W*0.001)	0.022	
		0.75: exponent in calculation	0.75	
r_{soil}	$r_{soil} = 0.1\, r$	Soil Intake Rate (g/d)	0.363515025	EPA Wildlife Exposure Factor Handbook, Vol. 1, p. 4-22
		r: food intake rate, g/d	3.635150245	
		0.1: amount of soil in diet, expressed as fraction of food diet, dry wt.	0.1	
T_{ls}	$T_{ls,\max,} = 1.02 M^{0.30}$	Maximum Lifespan	.324583901	Calder, p. 316, Table 11-5
		1.02: constant in equation	1.02	
		see above equation, M: body mass in kg (=W*0.001)	0.022	
		0.30: exponent in calculation	0.30	
r_b	$r_b = 0.481 M^{0.76}$	Inhalation rate (m^3/d)	0.026447603	Pedley, p. 15, Table V., adjusted to provide units of m^3/d
		0.481: constant in calculation to give m^3/d	0.481	
		M = body mass in kg	0.022	
		0.76: exponent in equation	0.76	
$r_{inhalation}$	$r_{inhalation} = x\ r_b$	Soil inhalation rate (g/d)	2.64476E-06	derived
		x: airborne dust loading, g/m^3	0.0001	
		r_b: inhalation rate (see above)	0.026447603	
I_w	$I_w = 0.099 M^{\ 0.90}$	Water consumption rate (L/d)	0.003190183	EPA Wildlife Exposure Factor Handbook, Vol. 1, p. 3-10, equation 3-17
		0.099: constant in equation	0.099	
		see above equation, M: body mass in kg (=W*0.001)	0.022	
		0.9: exponent in calculation	0.9	

Table 7.9 Part 2 of Dose Factors and Common Parameters Spreadsheet. Provides a reference source for all default internal dose conversion factors, and external dose conversion factors for water, sediment, and soil used in deriving the generic BCGs. These values, together with measured radionuclide concentrations in water, sediment, soil, and biota tissue data, can be used to estimate a dose to a receptor.

Nuclide	Dose Conversion Factors			
	Internal Dose	External Dose		
	Gy/y per Bq/kg (wet)	Water Gy/y per Bq/m^3	Sediment Gy/y per Bq/kg (dry)	Soil Gy/y per Bq/kg (dry)
^{241}Am	5.6E-04	1.4E-10	1.4E-07	2.9E-07
^{144}Ce	6.8E-06	3.4E-09	3.4E-06	6.8E-06
^{135}Cs	3.4E-07	1.4E-10	1.4E-07	2.8E-07
^{137}Cs	4.3E-06	2.0E-09	2.0E-06	4.0E-06
^{60}Co	1.3E-05	6.6E-09	6.6E-06	1.3E-05
^{154}Eu	7.6E-06	3.8E-09	3.8E-06	7.7E-06
^{155}Eu	6.2E-07	3.1E-10	3.1E-07	6.2E-07
^{3}H	2.9E-08	1.4E-11	1.4E-08	2.9E-08
^{129}I	4.5E-07	2.0E-10	2.0E-07	4.0E-07
^{131}I	2.9E-06	1.4E-09	1.4E-06	2.9E-06
^{239}Pu	5.3E-04	1.4E-11	1.4E-08	2.8E-08
^{226}Ra	3.0E-03	6.8E-09	6.8E-06	1.4E-05
^{228}Ra	3.6E-03	3.4E-09	3.4E-06	6.9E-06
^{125}Sb	2.7E-06	1.4E-09	1.4E-06	2.9E-06
^{90}Sr	5.7E-06	2.8E-09	2.8E-06	5.7E-06
^{99}Tc	5.1E-07	2.1E-10	2.1E-07	4.3E-07
^{232}Th	4.1E-03	3.0E-11	3.0E-08	6.1E-08
^{233}U	4.9E-04	9.3E-12	9.3E-09	1.9E-08
^{234}U	4.9E-04	3.2E-11	3.2E-08	6.5E-08
^{235}U	4.5E-04	9.4E-10	9.4E-07	1.8E-06
^{238}U	4.4E-04	2.3E-09	2.3E-06	4.6E-06
^{65}Zn	3.0E-06	1.5E-09	1.5E-06	3.0E-06
^{95}Zr	8.4E-06	4.2E-09	4.2E-06	8.4E-06

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8 Documenting Your Biota Dose Evaluation Results

At a minimum, your results shall be documented in your Annual Site Environmental Report (DOE 2000b). The following information shall be summarized in the Annual Site Environmental Report, and described in more detail within a report retained on file for future reference:

> **Printing the Results of Your Biota Dose Evaluation using the RAD-BCG Calculator**
>
> *Clicking on the "Set Print Area for Report" button at the bottom of the Aquatic or Terrestrial System Data Entry/BCG Worksheets, then pressing the printer icon in the toolbar, will print out a record of your biota dose evaluation. Sum of fraction totals, limiting organism types, and any changes you made to default parameters will be included.*

- Specify the biota dose limits being complied with (e.g., 1 rad/d for aquatic animals; DOE Order 5400.5).
- Identify the methods used to demonstrate compliance with these limits. Cite the method used (e.g., this technical standard). Describe the process used (e.g., general screening phase, site-specific analysis, actual biota dose assessment involving the collection and analysis of biota).
- Describe the area(s) of evaluation, sources of exposure, organism types, media types, and radionuclide data used in the evaluation.
- Summarize the results (e.g., sum of fractions for media and radionuclides are less than 1; doses calculated are less than biota dose limits) for the site area(s) of evaluation; and conclusions.
- Summarize why the evaluation was conducted, and how the results will be used (e.g., to demonstrate compliance with DOE dose limits, for use in outreach activities, in response to stakeholder or regulator requests, or for use in an eco-risk assessment.)
- All detailed information used in calculations (e.g., site-specific parameters selected and the rationale for their use) shall be described and retained on file for future reference.

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9 Example Applications of the Graded Approach

9.1 Generic Example of an Aquatic System Evaluation

This example was prepared using actual measured radionuclide concentration data from a DOE site. However, the data is used within a hypothetical context for a generic site (e.g., Poplar Springs Site, a hypothetical site). Two cases are provided, drawing from the same data set of measured radionuclide concentrations from surface water samples. The first case considers the entire Poplar Springs Site as the evaluation area, and options for proceeding when the Site fails a general screening evaluation. The second case begins with the goal of assessing several evaluation areas independently within the boundary of the Poplar Springs Site. The cases are intended only to highlight key steps and concepts of the graded approach, and to highlight several alternatives within each that would also result in a determination of protection relative to Dose Rate Guidelines.

Purpose:

The purpose of the evaluation was to demonstrate that the Poplar Springs Site (PSS) is in compliance with DOE's biota dose limit for aquatic animals pursuant to DOE Order 5400.5 II 3.a.(c)(5): "to protect native animal aquatic organisms, the absorbed does to these organisms shall not exceed 1 rad/d from exposure to the radioactive material in liquid wastes discharged to natural waterways."

1. Data Assembly *(Phase 1 of the Graded Approach)*:

A. Verify Data is Appropriate for a Biota Dose Evaluation

Surface water samples are collected and analyzed to assess the impact of past and current DOE operations on the quality of local surface water. Sampling locations include streams within the main plant area and at downstream locations from Poplar Springs Site (PSS) facilities; all are within the PSS boundary. These sampling stations are located within the Blue Falls Creek Watershed (main plant and down stream locations) and within other smaller watersheds, all of which flow into the Darlington River. Surface water data (via the surface water surveillance program) are collected throughout the year. The sampling frequency is dependant on historical data and the processes or legacy activities nearby or upstream from these locations. Therefore, sampling occurs at different locations monthly, bimonthly, quarterly, or semiannually. The sampling locations are presented in Table 1.

Table 1 Surface Water Sampling Locations for the Poplar Springs Site

Watershed	Sampling Locations
Blue Falls Creek	Two Falls Creek TFCK 0.5
Main Plant–On-site Stream Locations:	
	Broad Creek BRCK
	Northwest Tributary NWTK 0.5
Downstream Locations:	Muddy Branch MB 0.6
	Blue Falls Creek BFCK 3.0
	Blue Falls Creek at Blue Falls Dam BFCK 1.4
Other Watersheds Entering the Darlington River	Taylor's Creek TCK 1.0
	Beaver Creek BVCK 2.3

B. Request Sampling Data, to Include Maximum and Mean Water and Sediment Radionuclide Concentrations (co-located if possible) Collected for the Environmental Monitoring and Surveillance Program at Poplar Springs Site

Environmental surveillance surface water monitoring results were available. However, no on-site sediment data (co-located with water sampling stations) were available. The data were organized by collection location and summarized in a table for future use (Table 2). It was determined that the sampling locations indicated in Table 2 were each representative of individual evaluation areas within the larger Poplar Springs Site. Each of the evaluation areas were identified because they provide a good indication of potential impacts to biota in natural waterways within the Poplar Springs Site.

Table 2 Measured Radionuclide Concentrations (pCi/L) in Surface Water Collected from the Poplar Springs Site. Maximum, minimum, and average values are summarized. The maximum measured radionuclide concentrations observed for the Poplar Springs Site (i.e., across all sampling locations) are indicated by an (*).

Sampling Location	Radionuclide	Maximum	Minimum	Average
Main Plant: On-site station locations:				
Two Falls Creek (TFCK 0.5)	H-3	530	430	480
	Sr	15	15	15
Broad Creek (BRCK)	H-3	360	110	240
	Sr	290	59	170
	*U-234	36	7.7	22
	U-235	0.048	0	0.024
	U-238	0.52	0.28	0.40
Northwest Tributary (NWTK 0.5)	H-3	160	110	140
	Sr	71	1.8	36
Downstream Locations:				
Muddy Branch (MB 0.6)	*Co-60	4.6	-2.8	2.0
	Cs-137	3.0	0.0050	1.5
	*H-3	760,000	39,000	460,000
	*Sr	460	84	250
	U-234	0.52	0.15	0.33
	U-238	0.50	0.15	0.37
Blue Falls Creek (BFCK 3.0)	Co-60	1.5	0.034	0.79
	*Cs-137	67	12	37
	H-3	36,000	3,300	17,000
	Sr	330	28	100
	U-234	4.8	1.2	3.5
	*U-235	0.075	0	0.024
	*U-238	2.1	0.24	0.98
Blue Falls Creek at Blue Falls Dam (BFCK 1.4)	Co-60	3.9	0.58	2.5
	Cs-137	40	8.5	12
	H-3	140,000	32,000	71,000
	Sr	140	54	100
	U-234	8.2	1.6	5.0
	U-235	0.065	0	0.029
	U-238	1.6	0.41	0.95
Other watersheds entering the Darlington River:				
Taylor's Creek (TCK 1.0)	Co-60	3.2	0.64	1.9
Beaver Creek (BVCK 2.3)	Co-60	1.8	1.6	1.7
	H-3	330	180	260
	Sr	43	4.8	24

CASE 1. Use of Maximum Measured Radionuclide Concentrations for the Entire Poplar Springs Site

1. General Screening Evaluation *(Phase 2 of the Graded Approach)*

A. Enter Data into the RAD-BCG Calculator

Maximum measured radionuclide concentration data for surface water detected for the entire Poplar Springs Site (i.e., the radionuclide-specific maximum values detected across the entire Site) were entered into the Aquatic System Data Entry/BCG Worksheet within the RAD-BCG Calculator. The RAD-BCG Calculator automatically calculated the missing sediment radionuclide concentration data (e.g., by using the "most probable" radionuclide-specific K_d values) and entered the calculated radionuclide concentrations into the appropriate fields.

B. Compare Measured Radionuclide Concentrations in Environmental Media with BCGs

The RAD-BCG Calculator automatically calculated the radionuclide-specific partial sum of fractions for water and sediment, then calculated the total sum of fractions. A summary of the comparisons for each medium and radionuclide (which is similar in presentation to what you would see in the Aquatic System Data Entry/BCG Worksheet) is provided in Table 3. Note that this comparison could also be done manually by using Tables 6.1 - 6.2 and associated guidance contained in Module 1 of the DOE technical standard. The results indicated that the Poplar Springs Site failed the general screening evaluation using maximum radionuclide concentration data. Results also indicated that the water medium appears to be limiting (see partial sum of fractions for water and sediment, respectively, in Table 3). In addition, Cs-137 and Sr-90 were the radionuclides that provided the greatest contribution to the total sum of fractions (i.e., they were the most limiting radionuclides, providing the greatest contribution to potential dose). A riparian animal was indicated as the limiting organism type for these radionuclides.

Table 3 Aquatic System Evaluation: General Screening Results for Poplar Springs Site using Maximum Measured Radionuclide Concentrations in Surface Water Across the Entire Site

Radionuclide	Maximum Measured Radionuclide Concentrations (pCi/L)	Water Sum of Fractions	Sediment Sum of Fractions
H-3	760,000	2.9E-03	2.03E-06
Sr-90	460	1.70	2.37E-02
U-234	36	1.8E-01	3.42E-04
U-235	0.075	3.4E-04	1.01E-06
U-238	2.1	9.4E-03	4.22E-05
Co-60	4.6	1.2E-03	3.14E-03
Cs-137	67	1.6	1.07E-02
Total of partial sum of fractions for each medium		3.42	3.80E-02
Total sum of fractions for all radionuclides and media			3.45

2. Site-Specific Screening using Mean Radionuclide Concentrations in Place of Maximum Values *(Phase 3 of the Graded Approach: Analysis Phase, Site-Specific Screening)*

It was determined through consultation with site environmental surveillance program personnel that the quality and quantity of data allowed for averaging of measured radionuclide concentration data by individual sampling location for the Poplar Springs Site, but not across the entire Site. Guidance provided in Module 2, Section 3 of the DOE technical standard concerning spatio-temporal averaging, and guidance provided in Module 2, Section 4 concerning the definition of an evaluation area was reviewed. It was determined that - although the habitats and presence of the limiting organism type (in this case a riparian animal) were similar across all sampling locations, radionuclide data could not be averaged across the entire Poplar Springs Site because: (1) the site was too large for such an averaging scheme to be sensible, and (2) the contamination profiles (e.g., the radionuclides detected and their levels) for Main Plant - on-site locations, downstream locations, and other streams that enter the Darlington River were too different from one another (see Table 2). However, it was determined that within the downstream locations, data from Blue Falls Creek (BFCK 3.0) and Blue Falls Creek at Blue Falls Dam (BFCK 1.4) station locations could be averaged over space and time, because of their proximity to each other (e.g., both stations are in the same water system), and because the contamination profiles, habitats, and limiting organism type (riparian animal) were determined to be similar across the areas represented by these sampling locations. Therefore, measured radionuclide concentrations for these two locations were averaged for subsequent use in site-specific screening. Measured radionuclide concentrations for each of the remaining sampling locations were averaged by location, consistent with advice from the Site environmental surveillance program personnel.

A. Enter Data into the RAD-BCG Calculator

The averaging scheme presented above resulted in the need for seven separate evaluations: one for each of the six individual sampling locations, and one for the combined Blue Falls Creek / Blue Falls Creek at Blue Falls Dam locations. For each evaluation, mean measured radionuclide concentration data for surface water were entered into the Aquatic System Data Entry/BCG Worksheet within the RAD-BCG Calculator. The RAD-BCG Calculator automatically calculated the missing sediment radionuclide concentration data (e.g., by using the “most probable” radionuclide-specific K_d values) and entered the calculated radionuclide concentrations into the appropriate fields.

B. Compare Measured Radionuclide Concentrations in Environmental Media with BCGs

The RAD-BCG Calculator automatically calculated the radionuclide-specific partial sum of fractions for water and sediment, then calculated the total sum of fractions. A summary of the comparisons for each location is provided in Table 4. The results indicated that all of the sampling locations, each representing an individual evaluation area, passed the site-specific screening.

Table 4 Aquatic System Evaluation: Site-Specific Screening Results using Mean Radionuclide Concentrations in Surface Water for Each Evaluation Area

Sampling Location	Average Concentrations Sum of Fractions < 1.0 (Pass/Fail)?	Water Sum of Fractions	Sediment Sum of Fractions	Total Sum of Fractions
Main Plant - On-site Locations:				
Two Falls Creek (TFCK 0.5)	passed	5.39E-02	7.73E-04	0.055
Broad Creek (BRCK)	passed	7.21E-01	8.98E-03	0.73
Northwest Tributary (NWTK 0.5)	passed	1.29E-01	1.86E-03	0.13
Downstream Locations:				
Muddy Branch (MB 0.6)	passed	9.38E-01	1.45E-02	0.95
Blue Falls Creek (BFCK 3.0) and Blue Falls Creek at Blue Falls Dam Station (BFCK 1.4) (combined)	passed	0.96	1.03E-02	0.97
Other Streams that enter Darlington River:				
Taylor's Creek (TCK 1.0)	passed	5.05E-04	1.3E-03	0.002
Beaver Creek (BVCK 2.3)	passed	8.66E-02	2.4E-03	0.089

3. Documentation of Results

The results of the biota dose evaluation were summarized. A summary report which contains computer screen printouts of the spreadsheet results from the RAD-BCG Calculator were retained on file for future reference. The rationale for using average radionuclide concentration values in place of maximum values was documented. As required by EH, a summary of the evaluation was included in the Poplar Springs Site's Annual Site Environmental Report.

4. Lessons Learned

- All of the downstream station locations corresponding to individual evaluation areas provided the greatest total sums of fractions. These are clearly good indicator locations for future biota dose evaluations.

- All of the evaluation areas passed. However, because the total sum of fractions for each of the downstream locations was very near 1.0, we could consider conducting additional analysis on these evaluation areas using the analysis phase of the graded approach (refer to the example provided in CASE 2).

- Possible future activities could include: (1) assessing the need for additional sampling locations; (2) collecting co-located sediment and water samples for these and other locations; (3) collecting representative receptors and analyzing tissue data to permit a direct and more realistic dose evaluation.

CASE 2. Evaluation of Several Evaluation Areas Using Maximum Measured Radionuclide Concentration Data

1. General Screening Evaluation *(Phase 2 of the Graded Approach)*

A. Enter Data into the RAD-BCG Calculator

Maximum measured radionuclide concentration data for surface water for each sampling location (each representative of individual evaluation areas) were entered into the Aquatic System Data Entry/BCG Worksheet within the RAD-BCG Calculator (i.e., in this case, eight individual evaluations, one for each sampling location representative of an evaluation area, were conducted). The RAD-BCG Calculator automatically calculated the missing sediment radionuclide concentration data (e.g., by using the "most probable" radionuclide-specific K_d values) and entered the calculated radionuclide concentrations into the appropriate fields.

B. Compare Measured Radionuclide Concentrations in Environmental Media with BCGs

The RAD-BCG Calculator automatically calculated the radionuclide-specific partial sum of fractions for water and sediment, then calculated the total sum of fractions. A summary of the comparisons for each location is provided in Table 5. The results indicated that four of the locations evaluated (Broad Creek, Muddy Branch, Blue Falls Creek, and Blue Falls Creek at Blue Falls Dam) failed the general screening evaluation using maximum radionuclide concentration data. Results also indicated that the water medium is limiting (see partial sum of fractions for water and sediment, respectively, in Table 5). It was also determined that Cs-137 and Sr-90 were the radionuclides that provided the greatest contribution to the total sum of fractions (i.e., they were the most limiting radionuclides, providing the greatest contribution to potential dose). A riparian animal was the limiting organism type for these radionuclides.

Table 5 Aquatic System Evaluation: General Screening Results for Poplar Springs Site Using Maximum Measured Radionuclide Concentrations in Surface Water

Sampling Locations	Sum of Fractions < 1.0 (Pass/Fail?) Using Maximum Concentrations	Water Sum of Fractions	Sediment Sum of Fractions	Total Sum of Fractions
Main Plant--On-site Locations:				
Two Falls Creek (TFCK 0.5)	passed	5.39E-02	7.7E-04	0.05
Broad Creek (BRCK)	failed	1.22	1.53E-02	1.24
Northwest Tributary (NWTK 0.1)	passed	2.55E-01	3.66E-03	0.26
Downstream Locations:				
Muddy Branch (MB 0.6)	failed	1.73	2.73E-02	1.76
Blue Falls Creek (BFCK 3.0)	failed	2.79	2.88E-02	2.82
Blue Falls Creek at Blue Falls Dam (BFCK 1.4)	failed	1.49	1.64E-02	1.51
Other Streams that enter Darlington River:				
Taylor's Creek (TCK 1.0)	passed	8.51E-04	2.19E-03	0.003
Beaver Creek (BVCK 2.3)	passed	1.55E-01	3.45E-03	0.16

2. Site-Specific Screening using Mean Radionuclide Concentrations in Place of Maximum Values ***(Phase 3 of the Graded Approach: Analysis Phase, Site-Specific Screening)***

It was determined through consultation with Site environmental surveillance program personnel that the quality and quantity of data provided for time averaging of measured radionuclide concentration data for each individual evaluation area. Guidance provided in Module 2, Section 2 of the DOE technical standard concerning spatio-temporal averaging was also consulted.

A. Enter Data into the RAD-BCG Calculator

Mean radionuclide concentration data for surface water from each of the four sampling locations which failed the general screening phase were entered into the Aquatic System Data Entry/BCG Worksheet within the RAD-BCG Calculator (i.e., four separate evaluations were conducted). The RAD-BCG Calculator automatically calculated the missing sediment radionuclide concentration data (e.g., by using the "most probable" radionuclide-specific K_d values) and entered the calculated sediment radionuclide concentrations into the appropriate fields.

B. Compare Measured Radionuclide Concentrations in Environmental Media with BCGs

The RAD-BCG Calculator automatically calculated the radionuclide-specific partial sum of fractions for water and sediment, then calculated the total sum of fractions. A summary of the comparisons for each location is provided in Table 6. The results indicated that of the four locations evaluated (Broad Creek, Muddy Branch, Blue Falls Creek, and Blue Falls Creek at Blue Falls Dam), Broad Creek, Muddy Branch, and Blue Falls Creek at Blue Falls Dam passed the site-specific screening evaluation using mean radionuclide concentration data. Results also indicated that for the remaining location (Blue Falls Creek - which did not pass the screen), the water medium is limiting (see partial sum of fractions for water and sediment, respectively, in Table 6). It was also determined that Cs-137 and Sr-90 were the radionuclides that provided the greatest contribution to the total sum of fractions (i.e., they were the most limiting radionuclides, providing the greatest contribution to potential dose).

Table 6 Aquatic System Evaluation: Site-Specific Screening Results for the Poplar Springs Site using Mean Radionuclide Concentrations in Surface Water

Sampling Location	Average Concentrations Sum of Fractions < 1.0 (Pass/Fail?)	Water Sum of Fractions	Sediment Sum of Fractions	Total Sum of Fractions
Main Plant--On-site Locations:				
Two Falls Creek (TFCK 0.5)	(passed in general screen)			--
Broad Creek (BRCK)	passed	7.21E-01	8.98E-03	0.73
Northwest Tributary (NWTK 0.5)	(passed in general screen)			--
Downstream Locations:				
Muddy Branch (MB 0.6)	passed	9.38E-01	1.45E-02	0.975
Blue Falls Creek (BFCK 3.0)	failed	1.25	1.17E-02	1.26
Blue Falls Creek at Blue Falls Dam (BFCK 1.4)	passed	6.70E-01	8.85E-03	0.68
Other Streams that enter Darlington River:				
Taylor's Creek (TCK 1.0)	(passed in general screen)			--
Beaver Creek (BVCK 2.3)	(passed in general screen)			--

3. Site-Specific Screening using Site-Representative Parameter Values in Place of Default Values *(Phase 3 of the Graded Approach, Site-Specific Screening)*

Further efforts were directed at modifying some of the default parameters used in the site-specific screening portion of the graded approach, replacing them with more site-representative values.

A. Review of Data and Parameters for Blue Falls Creek (BFCK 3.0)

Because both maximum and average surface water concentrations collected at Blue Falls Creek exceeded the BCGs in general screening and site-specific screening, respectively, it was necessary to review the data used, limiting organism type responsible for the BCGs, limiting media, and area of evaluation. A summary of this review is provided in Table 7.

Table 7 Review of Radionuclide Concentration Data and Limiting Organism Type to Determine Path Forward in the Biota Dose Evaluation

Review the Following:	Comment
Sampling/Data Frequency -- adequate?	Surface water samples were collected and analyzed bimonthly (Jan, March, May, Jul, Sep, Nov): considered to be adequate. Possible Future Activities: * Consider possible need to increase sampling frequency (contact appropriate personnel) * Consider collection of co-located sediment samples (see below)
Radionuclides of concern?	Cs-137 and Sr-90 are the limiting radionuclides contributing the most to the total sum of fractions at this location. Water is the limiting medium; sediment contributes to dose but is not the limiting medium. Maximum and average concentrations detected in surface water for this location: Cs-137: Maximum: 67; Average: 37 pCi/L Sr-90: Maximum: 330; Average: 100 pCi/L
Are the limiting organism types used to derive BCGs reasonable?	Riparian animal -- yes, this receptor is feasible for the evaluation area. Known to be resident.
Consider re-defining or modifying the evaluation area?	Radionuclide data was already time-averaged to generate mean concentrations which are representative of the evaluation area. The location from which the radionuclide concentrations were detected is considered to be a representative indicator for site impacts on natural waterways. No additional modifications to the delineation of the evaluation area will be conducted.

B. Consider Replacing Default Lumped Parameter Values with Site-Representative Values

The major issues for this evaluation were Cs-137 and Sr-90 surface water concentrations. Therefore, the focus was on the radionuclide-specific default lumped parameters used to derive the BCGs for these two radionuclides.

The Riparian Animal Spreadsheet contained in the RAD-BCG Calculator (and contained in Module 1 Table 7.2 of the DOE technical standard) was reviewed to identify the default lumped parameter values (see Table 8 below for a summary). Available site data was reviewed for site-representative lumped parameter values for riparian animals (the limiting organism type for Cs-137 and Sr-90). After making some preliminary inquiries with site personnel, it was determined that there were no easily-accessible site-specific lumped parameter data for riparian animals. A more extensive search could have been performed (e.g., making contact with other DOE site representatives; conducting a literature search), but it was decided to move on to the site-specific analysis component of the graded approach, focusing on reviewing and potentially modifying additional default parameters and assumptions used in the analysis phase.

Table 8 Default Lumped Parameter Values Used to Derive Generic Water BCGs for Riparian Animals

Radionuclide	Lumped Parameter Bq/kg (animal-wet weight) per Bq/L(water)	Comment
Cs-137	50,000	A preliminary search at the Site indicated no known or easily accessible site-specific data for estimating site-specific lumped parameters for riparian animals.
Sr-90	6,000	A preliminary search at the Site indicated no known or easily accessible site-specific data for estimating site-specific lumped parameters for riparian animals.

4. Site-Specific Analysis Using Site-Representative Parameter Values and Assumptions in Place of Default Values *(Phase 3 of the Graded Approach, Site-Specific Analysis)*

A. Review Default Parameter Values and Consider Replacing with Site-Representative Values

A number of default parameters which are used in estimating a riparian animal's internal dose can be considered for modification in site-specific analysis. The default parameters for a riparian animal were reviewed by accessing the Riparian Animal Spreadsheet in the RAD-BCG Calculator (also contained in Module 1, Tables 7.5 and 7.6 of the DOE technical standard). These parameters are summarized in Table 9 below.

Table 9 Review of Default Parameter Values for Possible Modification Using Site-Representative Values

Parameter	Default Value	Site-Specific Values?
Appropriate Riparian Receptor?	Raccoon	Default organism is known to be resident at the site.
Fraction of intake retained Cs-137 Sr-90	 1 0.3	No known site specific evaluations to conclude otherwise. Default values were used to be conservative.
Biological Decay Constant Cs-137 Sr-90	 2.24E-02 6.11E-04	No known site specific evaluations to conclude otherwise. Default values were used to be conservative.
Correction Factor for Area or Time	1.0	No known site specific evaluations to conclude otherwise. The organism would be expected to be resident in the evaluation area 100% of the time.
Dose Limits for Riparian Animals	0.1 rad/d	Default dose limit used for riparian animals. Can not be changed without DOE-EH-41 approval.
Body Mass	8800 g	Default value. Default value was used to be conservative.
Other Kinetic/Allometric Relationship Parameters	Allometric equations and related input parameters representing mechanisms to internal dose to a riparian animal.	A cursory review of the default values for these parameters was made. It was decided to use the default values and equations rather than to obtain more site-representative values for use in the kinetic/allometric models employed in the analysis phase of the graded approach. However, the aquatic animal food source B_{iv} value used as the default food source to the riparian animal was reviewed (in the Aquatic Animal Spreadsheet) and subsequently modified.

Each of the contributing parameters could have been reviewed in detail, with the objective of identifying values more representative of site-specific receptors. It was determined through contact with aquatic biologists and radioecologists at the Poplar Springs Site that a reasonable amount of data relating to bioaccumulation factors (B_{iv}s) for fish was available at relevant Poplar Springs Site locations for the Blue Falls Creek evaluation area. Data exists for fish at or near Blue Falls Creek (BFCK 3.0) for Cs-137 and there is some data for Sr-90 in whole fish collected on-site in nearby waterways having similar water chemistry. It was determined that these fish were representative of the expected food sources to a riparian animal at the evaluation area, and that their B_{iv}s would provide more representative food source values to a site-specific riparian animal, in place of the default values used. With the assistance of the aquatic specialists, site-specific Cs-137 and Sr-90 concentrations measured in fish and in surface water were used to estimate B_{iv}s applicable to the Blue Falls Creek evaluation area. The data and resulting B_{iv}s are shown in Tables 10 and 11.

Table 10 Site-Specific Bioaccumulation Information for Cesium-137

Species	Water Concentration (Bq/L)	Tissue Concentration (Bq/kg)[1]	Bioaccumulation Factor (L/kg)[2]	Reference
Bluegill	1.52 Bq/L	BFCK 2.9 (N=7): 7900 ± 3400 Bq/kg dw BFCK 2.3 (N=5): 4600 ± 752 Bq/kg dw	1040 605	PSS/TM-11295 - Third Report of the PSS BMAP for Blue Falls Creek Watershed and the Darlington River (Tables 8.2-water and 8.11-fish)
Sunfish (includes bluegill and redbreast sunfish)	5.2 Bq/L	BFCK 3.5 (N=8): 21600 ± 2200 Bq/kg dw BFCK 2.9 (N=8) 29800 ± 9100 Bq/kg dw BFCK 2.3 (N=8): 13600 ± 8400 Bq/kg dw	830 1150 520	PSS/TM-10804 - Second Report of the PSS BMAP for Blue Falls Creek Watershed and the Darlington River (Table 8.23) Water Data Table 5.2.26 Environmental Surveillance of the PSS and Surrounding Environs (ES/ESH-1/V2)
Redbreast Sunfish	1.52 Bq/L	BFCK 2.9 (N=5): 7600 ± 1300 Bq/kg dw	1000	PSS/TM-11295- Third Report of the PSS BMAP for Blue Falls Creek Watershed and the Darlington River (Tables 8.2-water and 8.11-fish)

[1] Tissue concentrations were measured in fish fillets. It is assumed that the tissue concentrations in fillets are representative of whole body concentrations. This is appropriate, given that Cs-137 is known to concentrate in muscle tissues.

[2] It is assumed that fish are about 80% water; therefore, the dry weight of fish is multiplied by 0.2 to convert dry weight to wet weight.

Table 11 Site-Specific Bioaccumulation Information for Strontium-90

Species	Water Concentration (Bq/L)	Tissue Concentration (Bq/kg)	Bioaccumulation Factor (L/kg)	Reference
Bluegill	4.8 Bq/L	520 ± 140 Bq/kg ww (1987) (Whole body) N=5	110	PSS/TM-10804 - Second Report of the PSS BMAP for Blue Falls Creek Watershed and the Darlington River (Table 8.1) Blue Falls Creek Water Data Table 2.2.1 Environmental Surveillance of the PSS and Surrounding Environs (ES/ESH-4/V2).
Gizzard Shad	4.8 Bq//L	370 ± 360 Bq/kg ww (1987) (Whole body) N=5	80	PSS/TM-10804 - Second Report of the PSS BMAP for Blue Falls Creek Watershed and the Darlington River (Table 8.1) Blue Falls Creek Water Data Table 2.2.1 Environmental Surveillance of the PSS and Surrounding Environs (ES/ESH-4/V2)
Largemouth Bass	4.8 Bq/L	230 ± 120 Bq/kg ww (1987) (Whole body) N=5	50	PSS/TM-10804 - Second Report of the PSS BMAP for Blue Falls Creek Watershed and the Darlington River (Table 8.1) Blue Falls Creek Water Data Table 2.2.1 Environmental Surveillance of the PSS and Surrounding Environs (ES/ESH-4/V2)

B. Modification of Default B_{iv} Values for Organisms Consumed by the Limiting Organism

The Aquatic Animal Spreadsheet within the RAD-BCG Calculator was accessed and the default B_{iv} values for Cs-137 and Sr-90 were reviewed. Based on literature reviews, calculated values (Table 10 and Table 11), and consultations with the aquatic specialists*,* the following site-specific B_{iv}s for fish were selected:

Cs-137: 1150 (L/kg). Most conservative estimated bioaccumulation factor for fish collected at or near the sampling location (BFCK 2.9).

Sr-90: 110 (L/kg). Most conservative estimated bioaccumulation factor for fish collected on the Poplar Springs Site.

Enter Site-Representative Parameter Values into the RAD-BCG Calculator

First, the "allometric BCGs" button on the Riparian Animal Spreadsheet of the RAD-BCG Calculator was selected. This selection allowed the calculation of BCGs using the kinetic/allometric method. Then, the Aquatic Animal Spreadsheet of the RAD-BCG Calculator was accessed, and the default B_{iv} values for Cs-137 and Sr-90 were replaced by entering the site-specific B_{iv} values listed above. A "user supplied value" message appeared in the Aquatic Animal Spreadsheet to provide a reminder that default values had been modified. The BCGs for Cs-137 and Sr-90 were automatically updated within the RAD-BCG Calculator to reflect these site-specific input values. The site-specific BCGs for these two radionuclides were shown in the Riparian Animal Spreadsheet, and in the Aquatic System Data Entry/BCG Worksheet - where our mean measured radionuclide concentration data was previously entered. A new partial and total sum of fractions were automatically calculated by the RAD-BCG Calculator.

Compare Measured Radionuclide Concentrations in Environmental Media with BCGs

Due to the adjustment of the Cesium-137 B_{iv} to 1150 and the Sr-90 B_{iv} to 110, the total sum of fractions for Blue Falls Creek was less than 1.0, indicating that we passed the site-specific analysis.

It is also noteworthy that - had we used the site-specific food source B_{iv} values compared with maximum measured radionuclide concentration data rather than mean values, the total sum of fractions for our riparian animal would also have passed. This would be a useful approach if we were required by regulators or stakeholders to use only maximum measured radionuclide concentrations in our evaluation. This point highlights one example regarding the flexibility of the graded approach.

5. Documentation of Results

The results of the biota dose evaluation were summarized. A summary report containing computer screen printouts of the spreadsheets from the RAD-BCG Calculator were retained on file for future reference. The rationale for selecting site-representative B_{iv}s as a food source value to a riparian animal was documented. As required by EH, a summary of the evaluation was included in the Poplar Springs Site's Annual Site Environmental Report.

6. Lessons Learned

- Possible future activities could include: (1) assessing the need for additional sampling locations; (2) collecting co-located sediment and water samples for these and other locations; (3) collecting representative receptors and analyzing tissue data to permit a direct and more realistic dose evaluation.